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Symposium

REVIEW OF WAR SURGERY

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September 1946

VOLUME LXXII NUMBER 3

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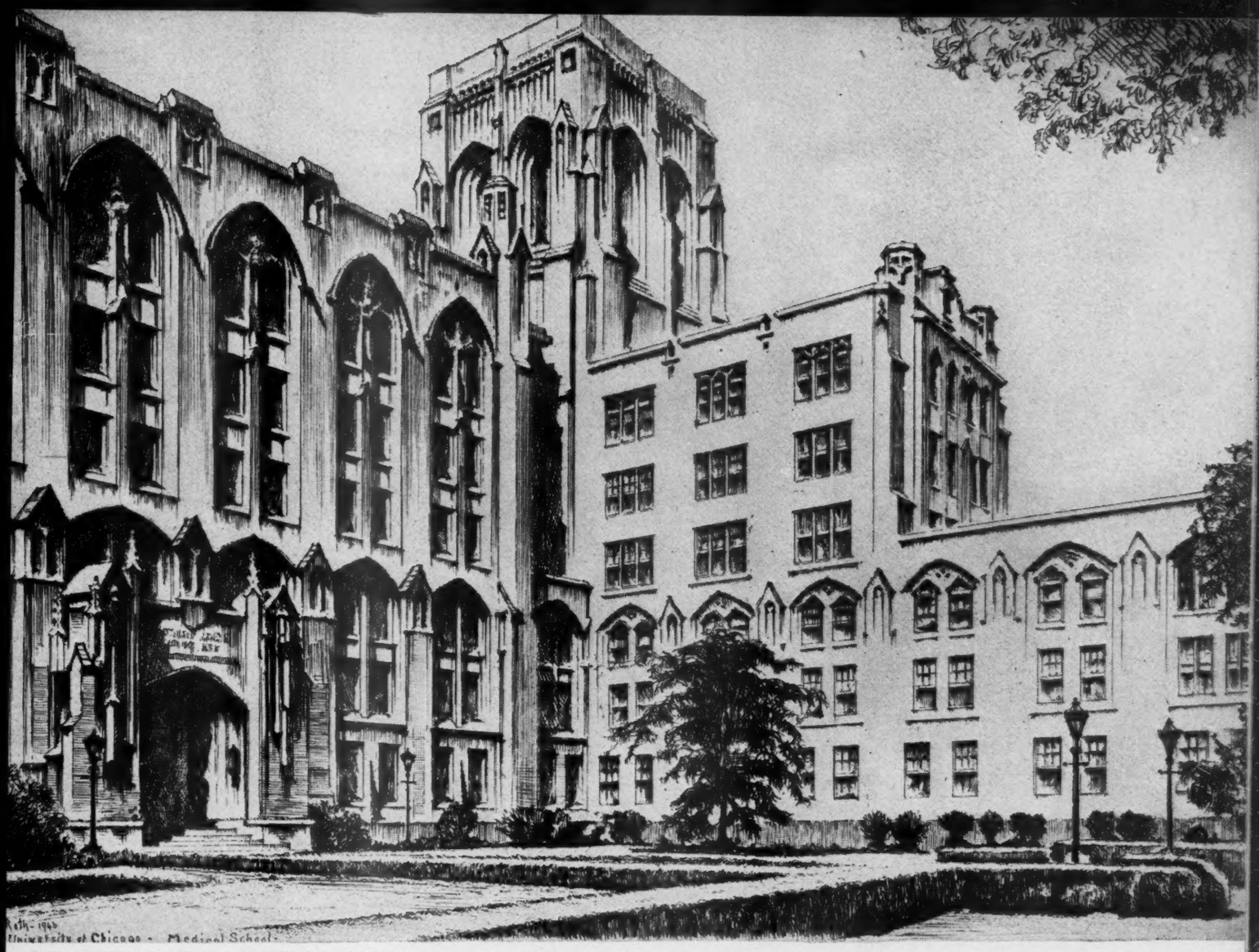

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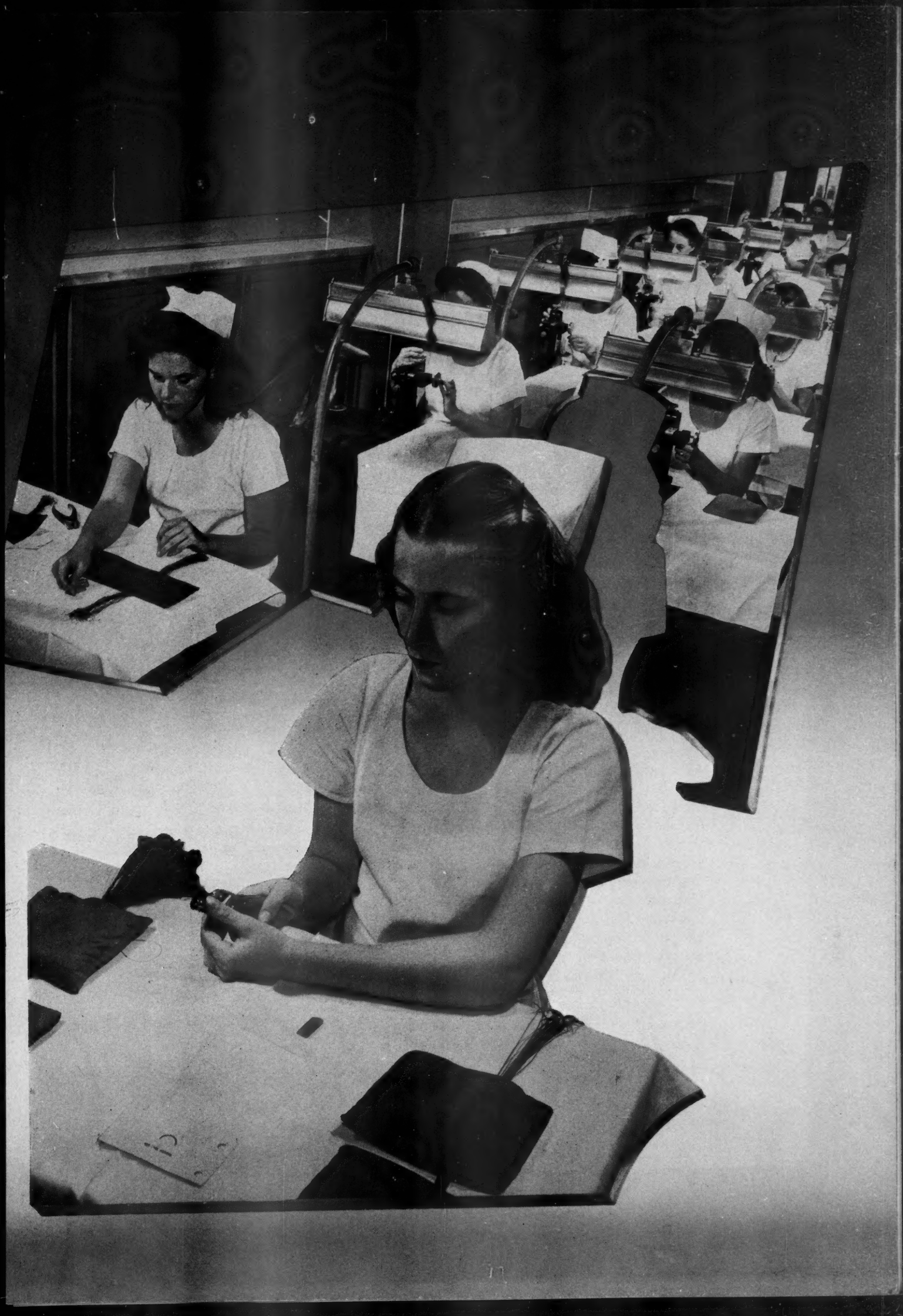

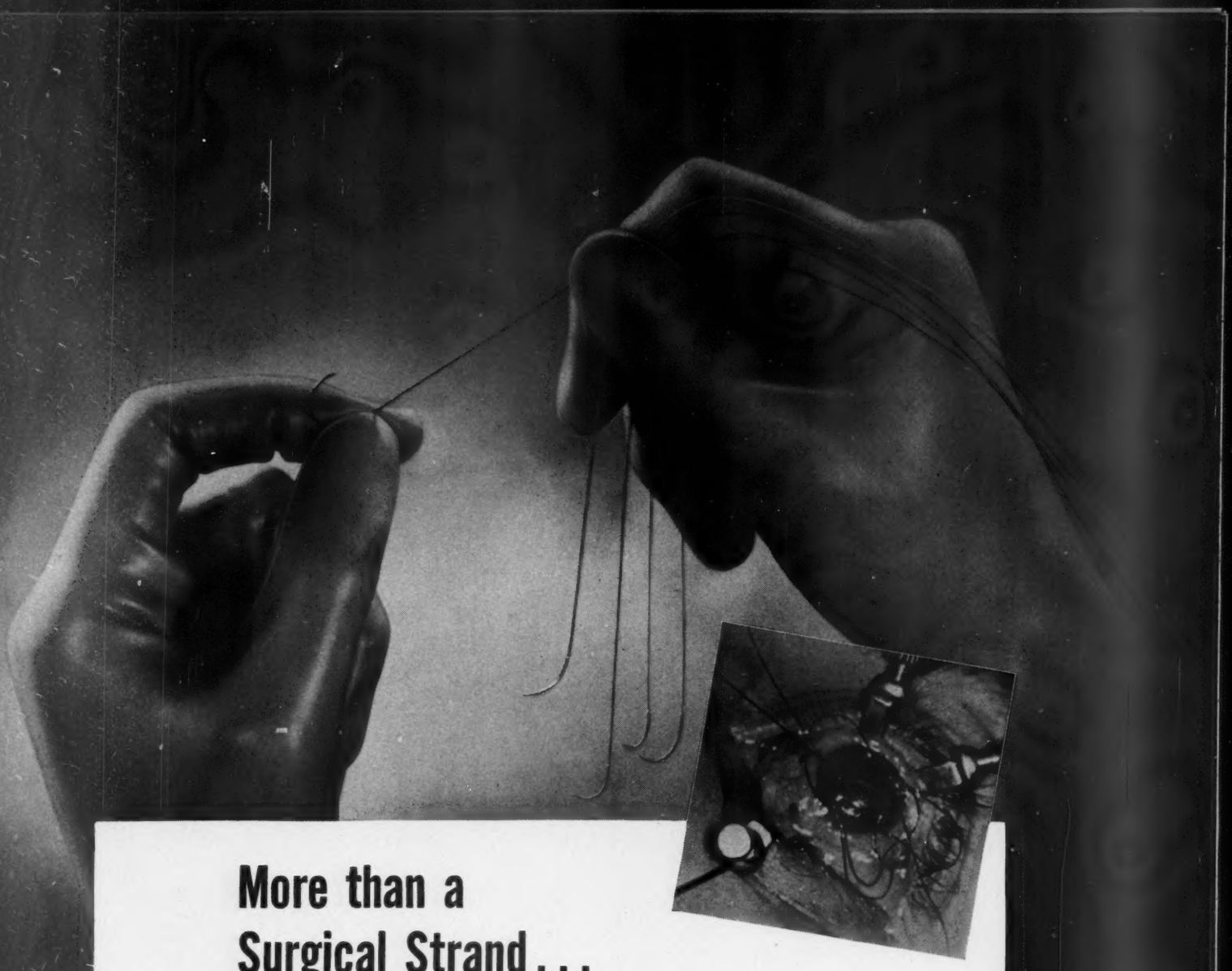

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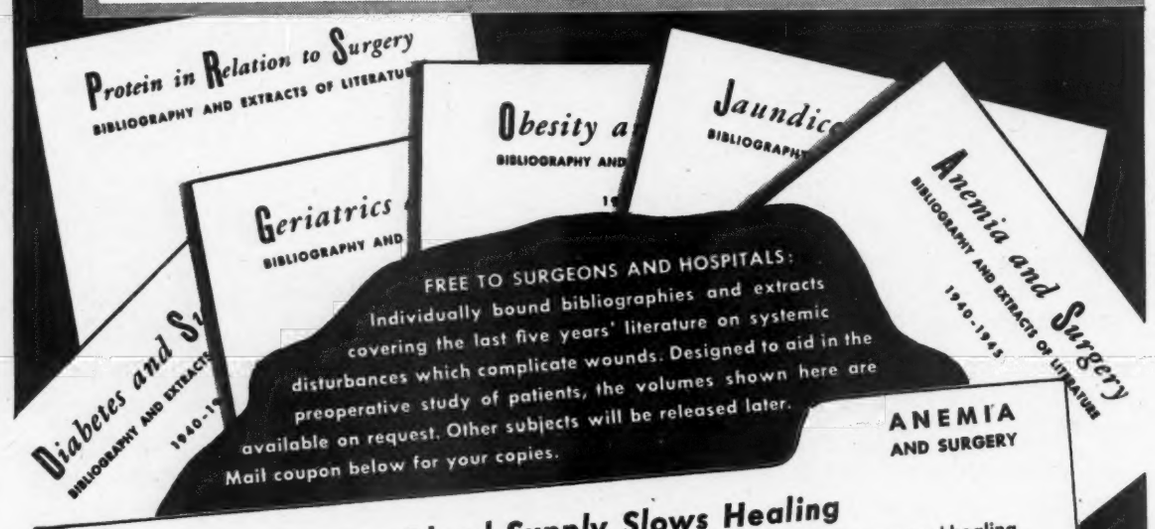
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*Sandblom, P.: Tensile Strength of Healing Wounds: Experimental Study. Acta Chir. Scandinav. 90: 71-72 (Supp. 89), 1944.

**Casper, M.: Lowering the Mortality of the Poor Surgical Risk. J. Indiana M.A. 35: 358-361, July, 1942.

***Mason, R. L., and Zintel, H. A.: Preoperative and Postoperative Treatment. Philadelphia, W. B. Saunders Co., 1946, pp. 13, 406, 448.

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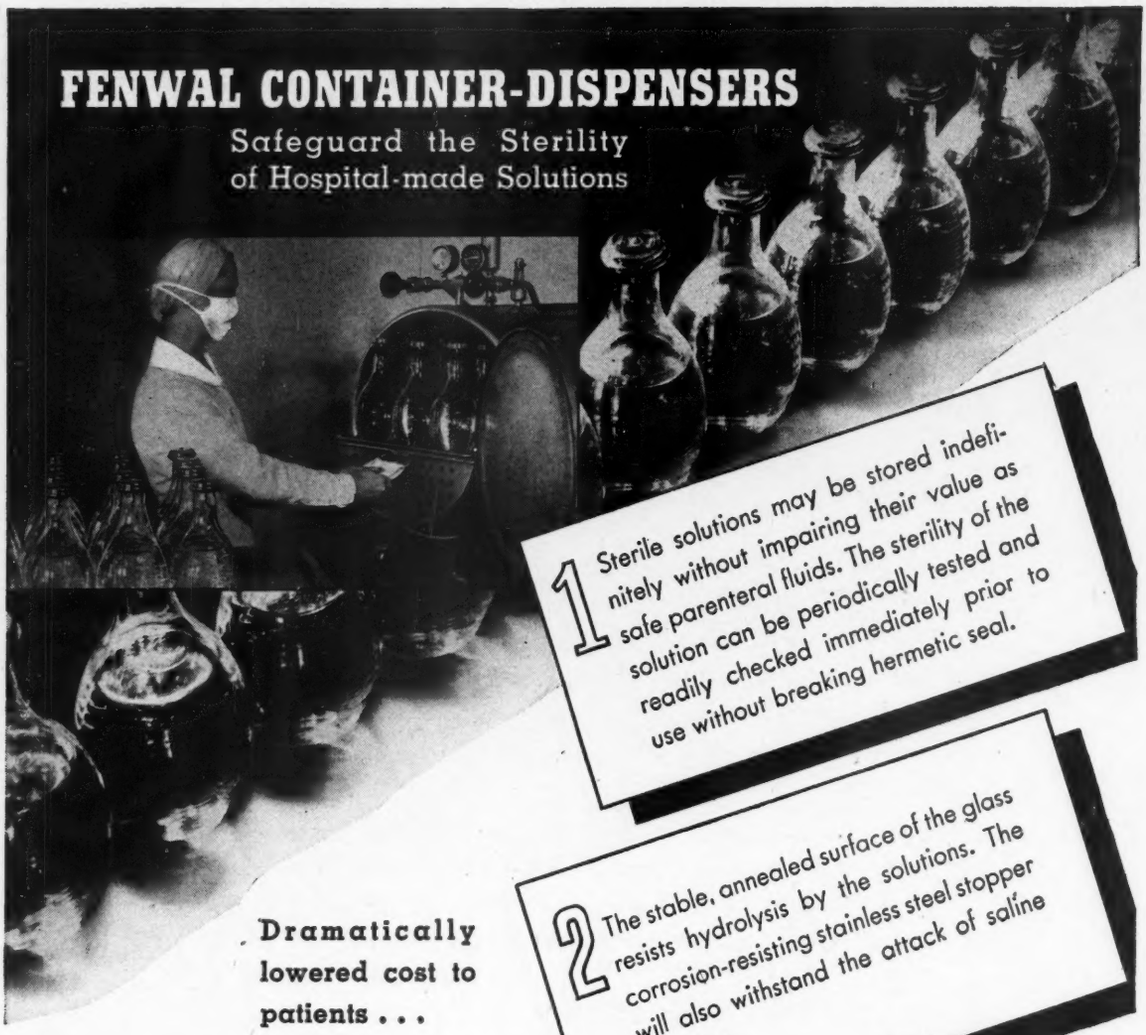

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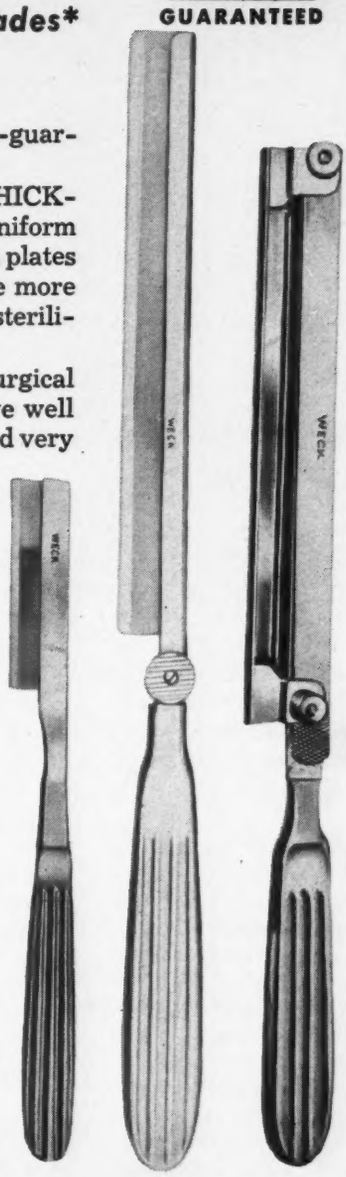

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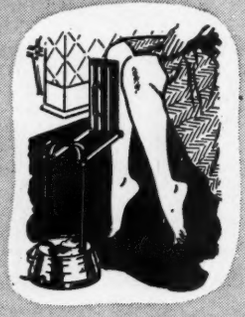
IN the management of many dermatologic and systemic affections maximal therapeutic results can only be obtained by daily ultraviolet ray therapy. In many instances such frequent office visits are not practical or feasible. In consequence, the occasion frequently arises when actinic ray therapy must be prescribed for home use for continuous treatment.

Its simplicity of operation and comparative safety make the ***Sun-Kraft*** Ultraviolet Ray Lamp especially adaptable for home use. This economical cold quartz ultraviolet generator is rapidly becoming the physician's choice when ultraviolet ray therapy must be continued between office visits. Although not originally intended for therapeutic use in the physician's office, its outstanding advantages have led to its ever increasing use for this purpose.

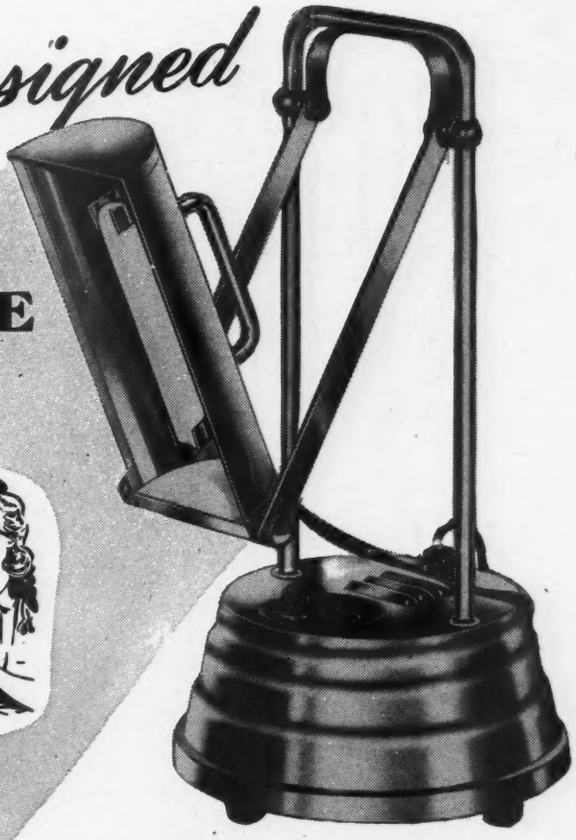
Based on its established cutaneous and systemic influences, ultraviolet light has been found therapeutically useful for:

- **Promotion of Normal Calcium and Phosphorus Metabolism**
- **Prevention and Cure of Rickets**
- **Prevention and Treatment of Infantile Tetany**
- **Aiding in the Development of Bones and Teeth**
- **Promotion of Healing of Skin Ulcers and Indolent Wounds**
- **Treatment of Many Skin Conditions such as Acne, Psoriasis, and Many Varieties of Eczema**
- **Treatment of Certain Types of Cutaneous and Subcutaneous Tuberculosis**
- **Treatment of Bone and Joint Tuberculosis**



The Sun-Kraft Ultraviolet Ray Lamp is conveniently available through dealers located in every section of the country.

Specifically designed for **HOME USE**



The Sun-Kraft Ultraviolet Ray Lamp possesses many unique advantages which make it especially adaptable for home use.

NO HEAT RAYS. Of the cold quartz type, the ***Sun-Kraft*** Lamp emits virtually no heat rays hence can be used safely and comfortably even in direct contact with the skin.

AUTOMATIC BUILT-IN TIMER. The automatic timer built into the ***Sun-Kraft*** Lamp eliminates the danger of overexposure due to misjudgment of time. It may be set either to control duration of application or for continuous operation.

BIOLOGICALLY ACTIVE ACTINIC RAYS. Extensive research in the Biophysical Department of a well-known American university* has shown that the ***Sun-Kraft*** Lamp emits a spectrum, 86% of which is in the potentially bactericidal, erythemic, and vitamin D-inducing zone—2537 Angström unit line.

CONVENIENCE. At the recommended operating distance of three inches, a well developed erythema is produced in the average previously unexposed skin in one minute. Flexibility of design permits convenient applications to any body part and easy removal of generator for use as a hand instrument.

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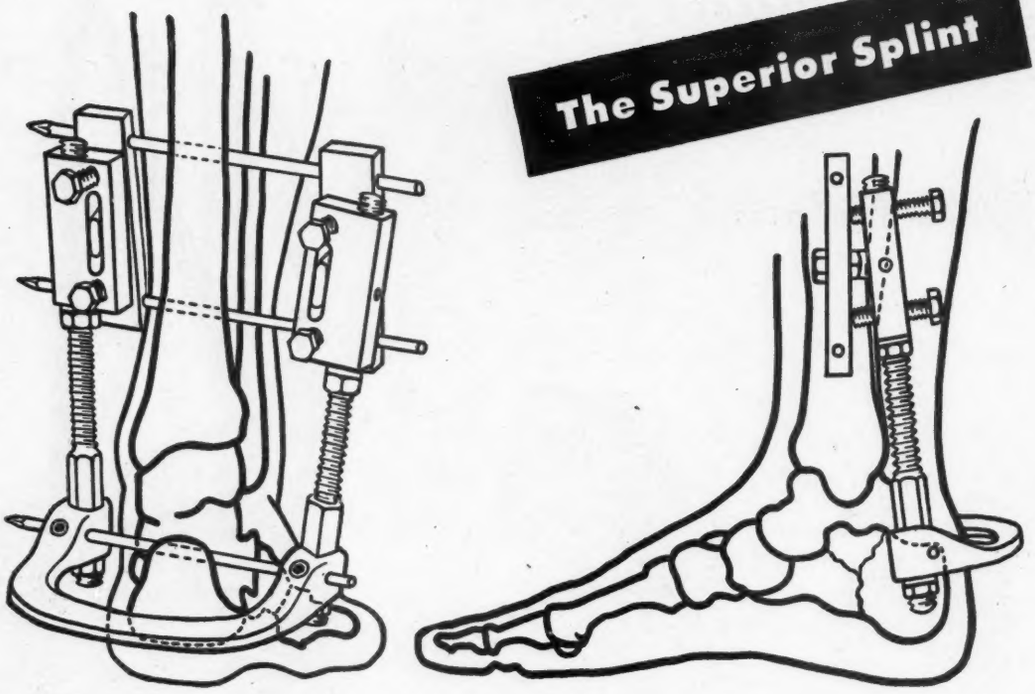
Sun-Kraft, Inc.

215-217 West Superior Street, Chicago 10, Illinois

THE *Sun-Kraft* LAMP



The Superior Splint

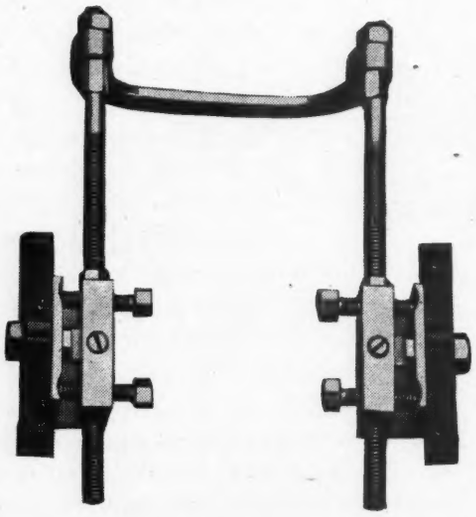
. . . for management of fractures of the Os Calcis

The Stader Splint effectively prevents contraction of both the Achilles tendon and the Plantar muscles. It assures absolute rigidity for the fractured bone fragments without resort to plaster, and provides for secondary adjustments should they be necessary.

The structural strength of Stader Splints permits maintenance of proper sub-astragaloid joint spacing and restoration of the tuber-joint angle during healing of fractures of the os calcis.

The adjustable features of Stader Splints allow positive lateral displacement with respect to the vertical anterior-posterior plane to effect complete anatomical correction of the os calcis.

You may obtain detailed information about Stader Splints by addressing your inquiries to General Electric X-Ray Corporation, 175 West Jackson Blvd., Chicago 4, Illinois. Dept. 2569.



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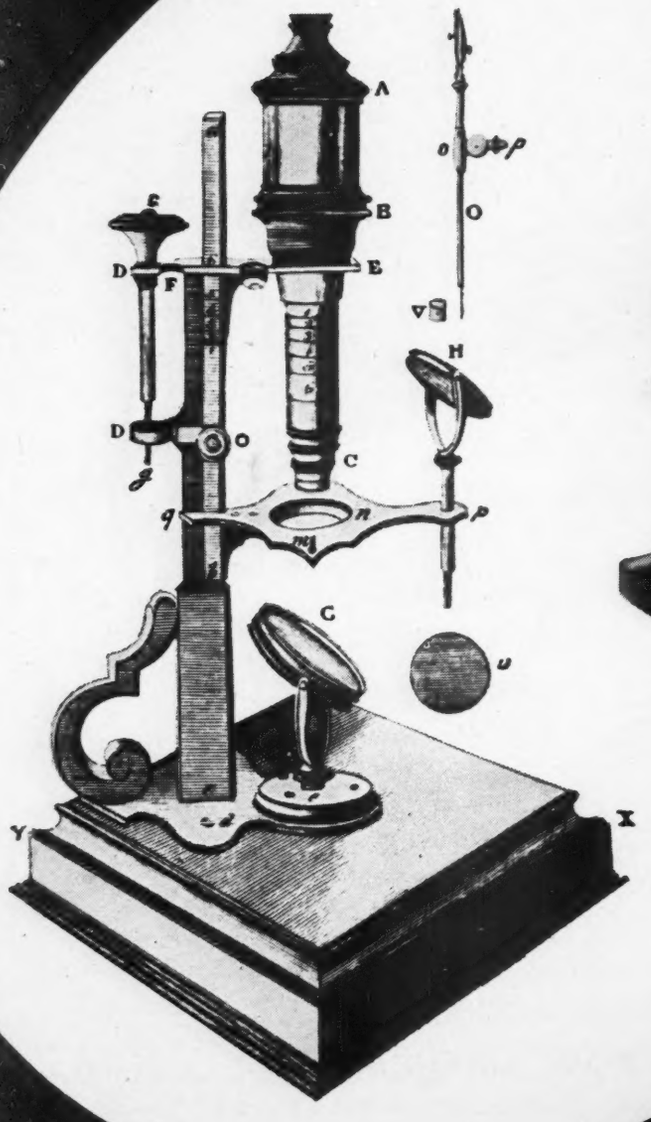

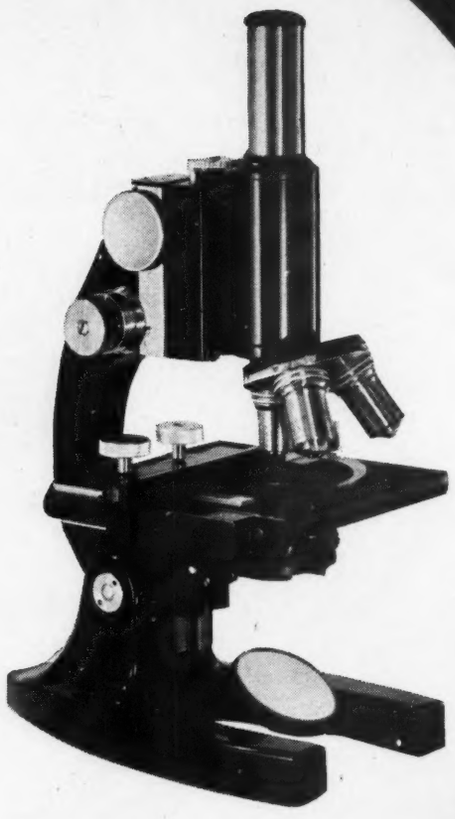

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anemias

Since the discovery of the microscope, years of research and patient effort have been spent in producing the modern magnificent instrument—a diagnostic aid and a guide to therapeusis of recognized demonstrable superiority.

In treatment of hypochromic (so-called "secondary") anemias Mol-Iron therapy—as compared to equivalent dosage of ferrous sulfate alone—achieves these strikingly superior clinical results:

1. Normal hemoglobin values are restored more rapidly, increases in the rate of hemoglobin formation being as great as 100% or more in patients studied.
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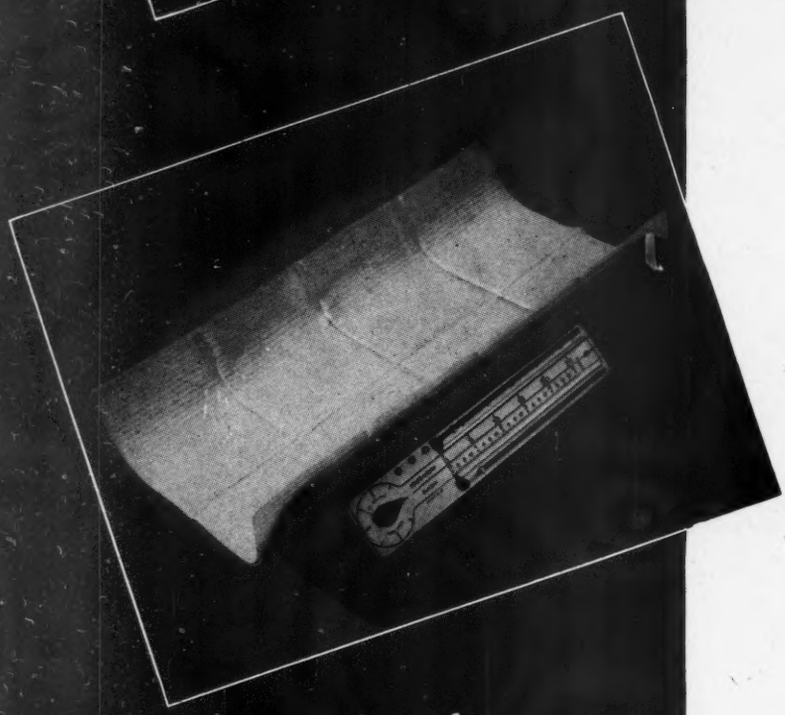
3. Gastro-intestinal tolerance is excellent—even among patients who have previously shown marked gastro-intestinal reactions following oral administration of other iron preparations.

White's Mol-Iron is a *specially processed*, co-precipitated complex of molybdenum oxide 3 mg. (approx. 1/20 gr.) and ferrous sulfate 195 mg. (3 gr.).

In bottles of 100 and 1000 tablets.

M

Tablets



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- ***On examining tables and instrument trays.***
- ***Wiping instruments after use.***
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- ***Colostomy dressings.***

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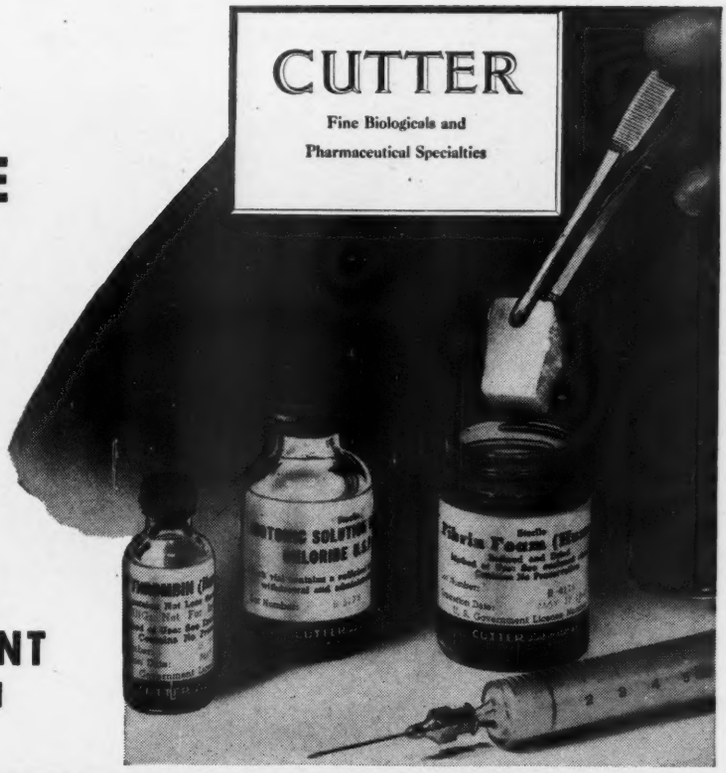
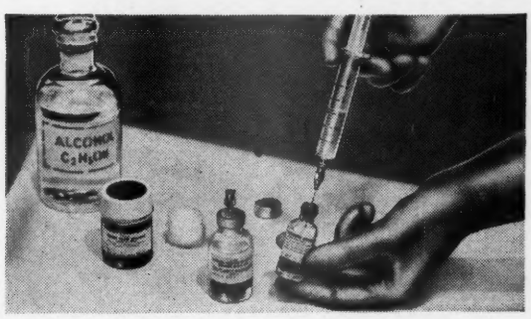
HOW TO USE FIBRIN FOAM

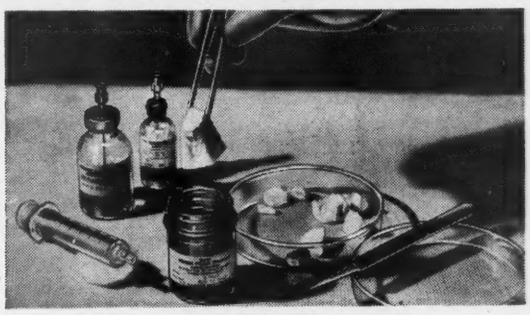
CUTTER'S WAR-PROVEN HEMOSTATIC AGENT

Made from Human Blood





1. Fibrin Foam and Thrombin come in 3 vials—the foam, dried thrombin, and isotonic sodium chloride. Dissolve sterile thrombin by adding 3 to 4 cc. physiological saline. Transfer Fibrin Foam to aseptic container, use wide-mouthed sterile bottle for dilution of thrombin solution.



3. Moisten Fibrin Foam in thrombin solution just before applying to freshly sponged bleeding area. Apply gentle pressure for a moment until clot forms; then leave in place to be absorbed. Made from proteins of pooled normal blood plasma, it is homologous, non-reactive.

2. Fibrin Foam in the dry state cuts easily to any size with scalpel or razor blade. A selection of various-sized pieces, ready to moisten in solution, saves sponging time. The dry sponge is light, permeable and rather brittle; when wet, it becomes soft, pliable and slightly resilient.

An outgrowth of research in human plasma fractionation at Harvard Medical School, Cutter's Fibrin Foam is made from human blood—thus is a non-reacting, absorbable homologue. Offers outstanding advantages in all types of surgery where hemostats and sutures are impractical.

FOR COMPLETE INFORMATION
on Fibrin Foam and other important human blood fractions, write for Cutter's new BLOOD FRACTIONS booklet. Cutter Laboratories, Berkeley, California

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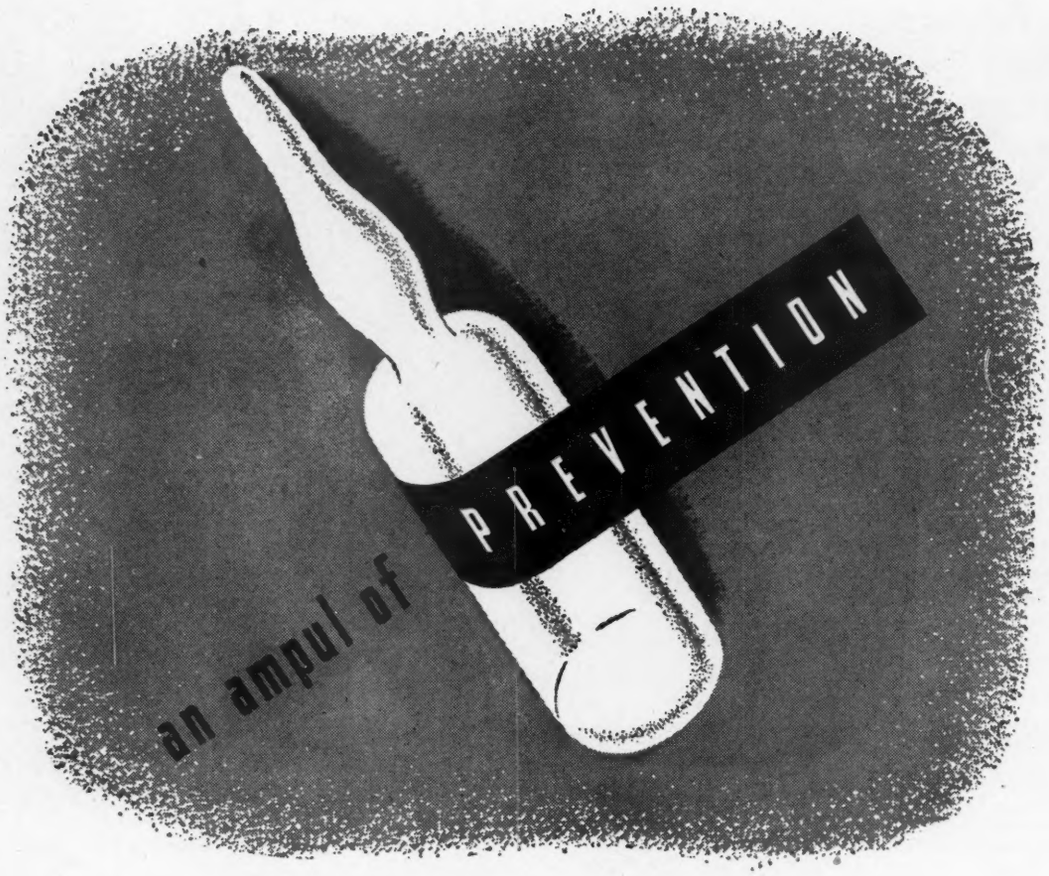
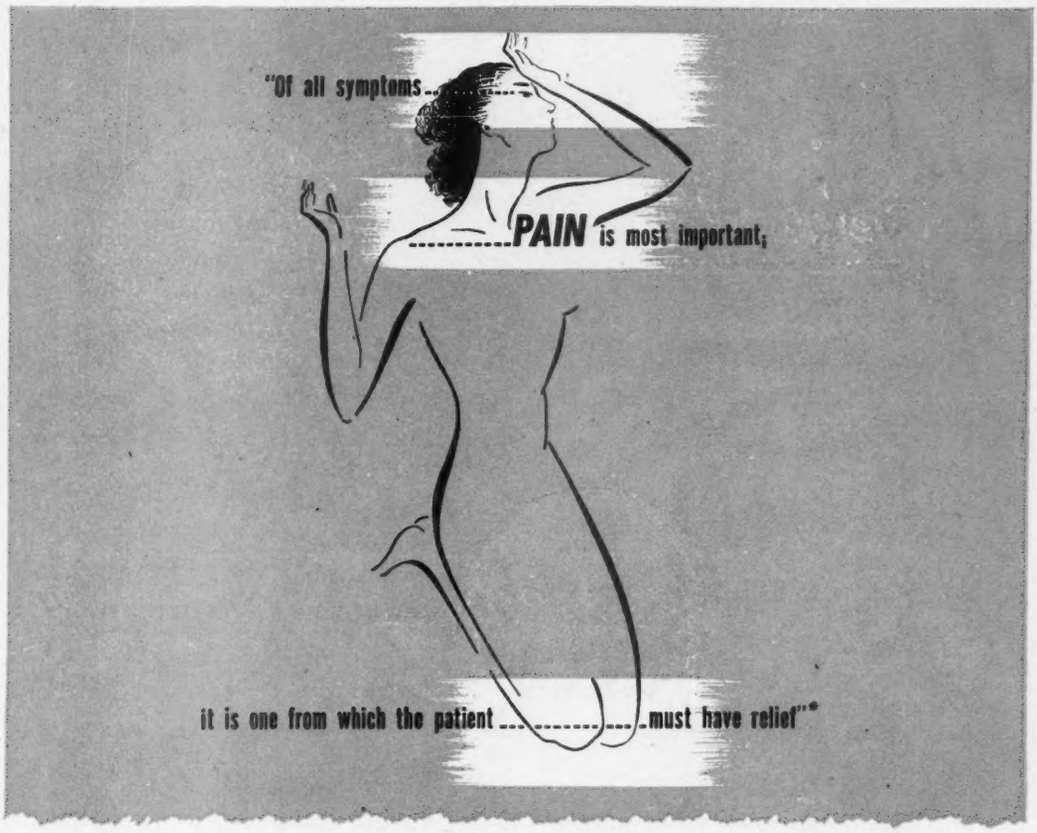


Postoperative distention and urinary retention may occur despite the most skilful surgical technic. Fortunately, the severe distress of "gas pains," discomfort of catheterization, and the need for enemas and symptomatic therapy may be obviated—and the patient afforded a smoother convalescence—by parenteral administration of one ampul (1 cc) of Prostigmin Methylsulfate* 1:4000 at the time of operation, repeated at 2-hour intervals for a total of 6 injections. Recognition of this fact by leading surgeons has made the prophylactic use of Prostigmin a routine measure in many hospitals.

HOFFMANN-LA ROCHE, INC., Roche Park, Nutley 10, New Jersey

*Neostigmine Methylsulfate

Prostigmin 'ROCHE'



Wherever a general analgesic-sedative is indicated,

Aspirocal

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offers three important drugs for their synergistic pharmacologic effect—the potentiation of analgesia.

Formula

Each Tablet Aspirocal Comp. contains:
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Calcium Gluconate.....2 gr.
Butisol (5-ethyl-5-secondary butyl barbituric acid "McNeil").....⅓ gr.

Supplied in bottles of 100, 500 and 1000 tablets.

*Handbook of Therapy, Chicago, American Medical Association, 1935, p. 58.

Aspirocal—although designed for general analgesic and sedative use—requires your prescription. Thus the patient is kept under your absolute supervision and the causation of pain can be checked.

Aspirocal is widely used in headache, the large field of neuralgias and similar conditions, rheumatic and arthritic conditions, and in dysmenorrhea and minor surgical procedures. Caution: Use only as directed.

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50,000 UNITS OF
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More comfort during maintenance of penicillin blood levels

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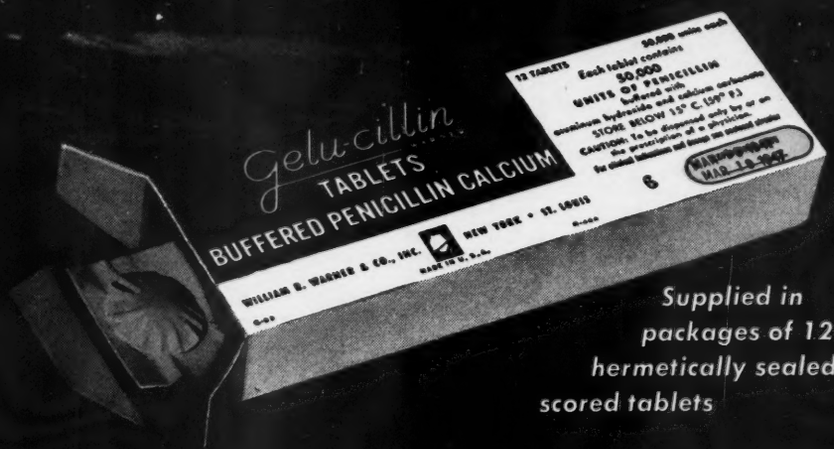

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to combat

mental depression in the menopause

". . . because the involutional period is fraught with sadness the different forms of mental disorder of this age may be highly colored with mental depression."*

Severe menopausal depression, marked by apathy and psychomotor retardation, is frequently progressive. Hence, if not promptly and effectively treated, it may seriously impair the patient's normal capacity for useful living.

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*Hinsie, Leland E.: The Person in the Body, an Introduction to Psychosomatic Medicine, New York, W. W. Norton & Co., 1945, p. 223.

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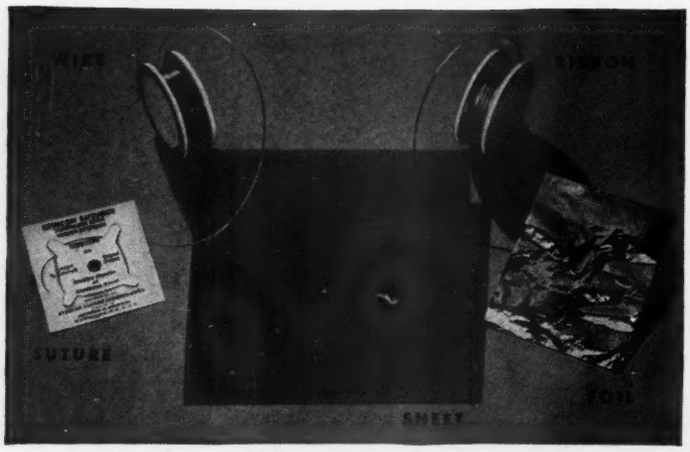
"I have used tantalum wire suture material on all our hand injury cases for the past year and have a large series of them to look back upon. I have used the tantalum wire for both buried and cutaneous suturing. In this fairly large series of cases I have not yet seen any evidence of anything but minimal tissue reaction. I have not yet had a single infection in any of the cases where tantalum wire was used in these hand cases, which, to me, is quite remarkable because I am sure you will appreciate how difficult it is to obtain bacterial and physical cleanliness in working with the hand of the factory worker.*"



*Olson, C. T.: "The Place of Tantalum in Surgery," Industrial Medicine, 13: 917, November, 1944.

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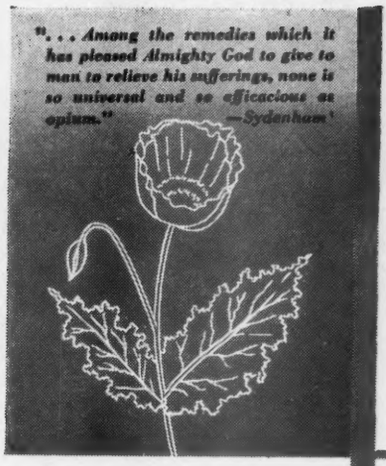
"... Among the remedies which it has pleased Almighty God to give to man to relieve his sufferings, none is so universal and so efficacious as opium." —Sydenham[1]

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A POTENT NEW SYNTHETIC SURPASSING THE OPIATES

DEMEROL ... chemically unrelated to the opiates by structure or derivation, yet "more suitable than morphine or any of its derivatives for controlling pain."[2] Demerol is the first synthetic drug to produce morphine-like analgesia — is similar to atropine and papaverine in antispasmodic effects ... well tolerated ... non-constipating... essentially free of depressant effects..."In clinical doses the addiction liability of Demerol is less than that of morphine."[3]

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ANALGESIC — effective, essentially, as morphine with fewer and less disturbing side effects.

ANTISPASMODIC — to provide dramatic relief of colicky pain due to visceral spasm.

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Subject to Federal and State Narcotic Regulations.

[1] Goodman, L., and Gilman, A. : The Pharmacological Basis of Therapeutics, New York, The Macmillan Company, 1941, p. 186.
[2] Batterman, R. C., and Mulholland, J. H. : Arch. Surg. 46:404, 1943.
[3] Himmelsbach, C. K. : J. Pharmacol. & Exper. Therap. 79:5, 1943.

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Furacin Soluble Dressing contains 0.2% of this new antibacterial (5-nitro 2-furaldehyde semicarbazone), in an anhydrous base composed of carbowax (75%) and propylene glycol (25%). It melts at body temperature; its low surface tension facilitates spreading to all parts of wounds. Being water soluble, it mixes with wound exudates, penetrating pockets of pus and blood. It does not macerate the skin; is not irritating to tissue; does not retard the healing rate of wounds.

Full details will be sent you on request to The Medical Director, Eaton Laboratories, Inc., Norwich, New York.

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NORWICH, NEW YORK

1. Neter, E., & Lambarti, T. G., Am. J. Surgery. In press
2. Snyder, M. L., Kiehn, C. L., & Christopherson, J. W., Military Surgeon *97*:380, 1945
3. Dodd, M. C., & Stillman, W. B., J. Pharmacol. & Exper. Therap. *82*:11, 1944
4. Cramer, D. L., & Dodd, M. C., J. Bacteriology *51*:293, 1946
5. Krantz, J. C., & Evans, W. E., J. Pharmacol. & Exper. Therap. *85*:324, 1945

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control . . .

Control of capillary and venous bleeding reduces blood loss during operative and postoperative period procedures. Therapeutically for use in the control of bleeding in hemoptysis, epistaxis, bleeding ulcers, hematuria, the purpuras and hemophilia. KOAGAMIN* diminishes blood loss by the patient. Saves time for the physician.

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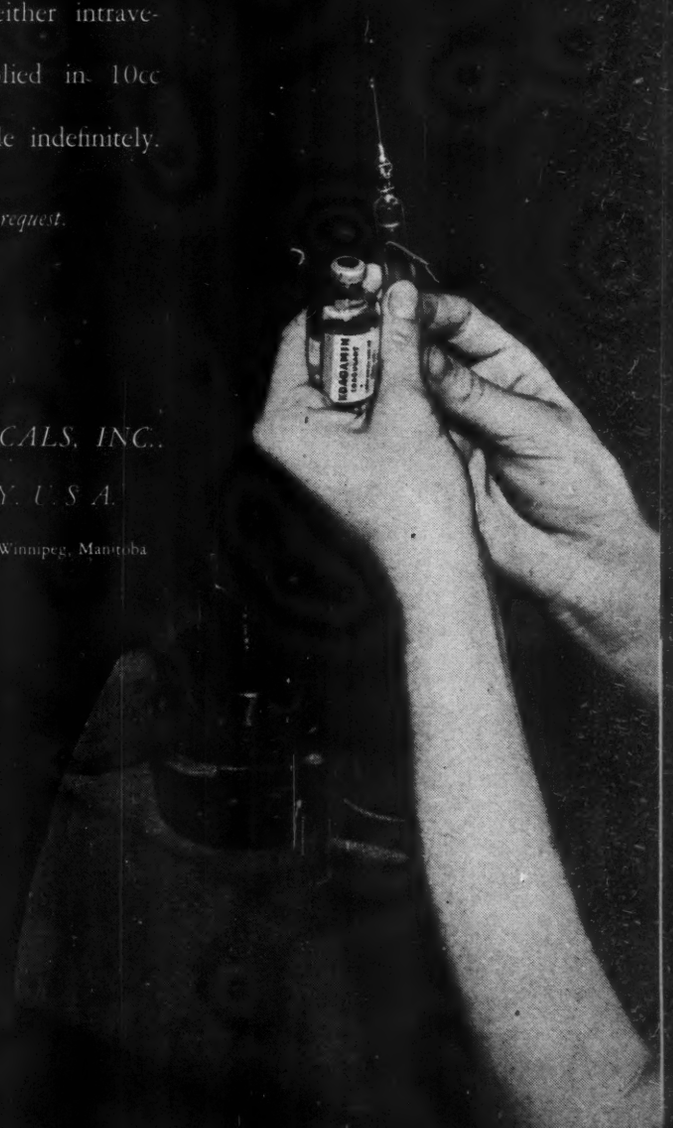

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Multiphasic Therapy

in the SYSTEMIC APPROACH TO ARTHRITIS

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Vitamin B_1 (Thiamine Hydrochloride)	3 mg.
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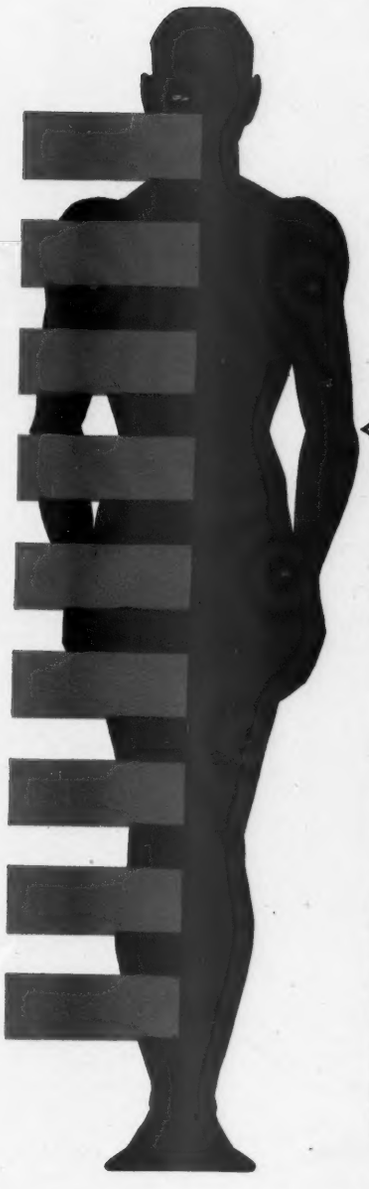
Niacinamide	15 mg.
Calcium Pantothenate	1 mg.
*Mixed Natural Tocopherols	3.4 mg.

* Equivalent in biological activity to 3 mg. of Alpha Tocopherol



"Rheumatoid arthritis is a systemic disease; the patient must be treated as a whole, rather than have local treatment to his joints alone."*

THIS statement by the American Rheumatism Association Committee is the keynote of the present successful method of treating arthritic patients. To produce the best results anti-arthritic therapy must combat not only the joint changes, but also the systemic disturbances so frequently encountered in chronic arthritis. This systemic approach requires a multiphasic therapeutic regimen which must include correction of disturbed physiologic functions, optimal nutrition, elimination of foci of infection, mental and physical rest, supervised exercise, physical therapy, and orthopedic measures.

Because of its rational composition, Darthronol merits inclusion in every anti-arthritic program. The combined pharmacodynamic and nutritional influence of its nine active ingredients makes it an efficacious therapeutic measure whenever the chronic arthritides must be combated.

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*The Primer on Arthritis prepared by a Committee of The American Rheumatism Association and published in The Journal of the American Medical Association, volume 119, page 1089, August 1, 1942.

Complete bibliography on request

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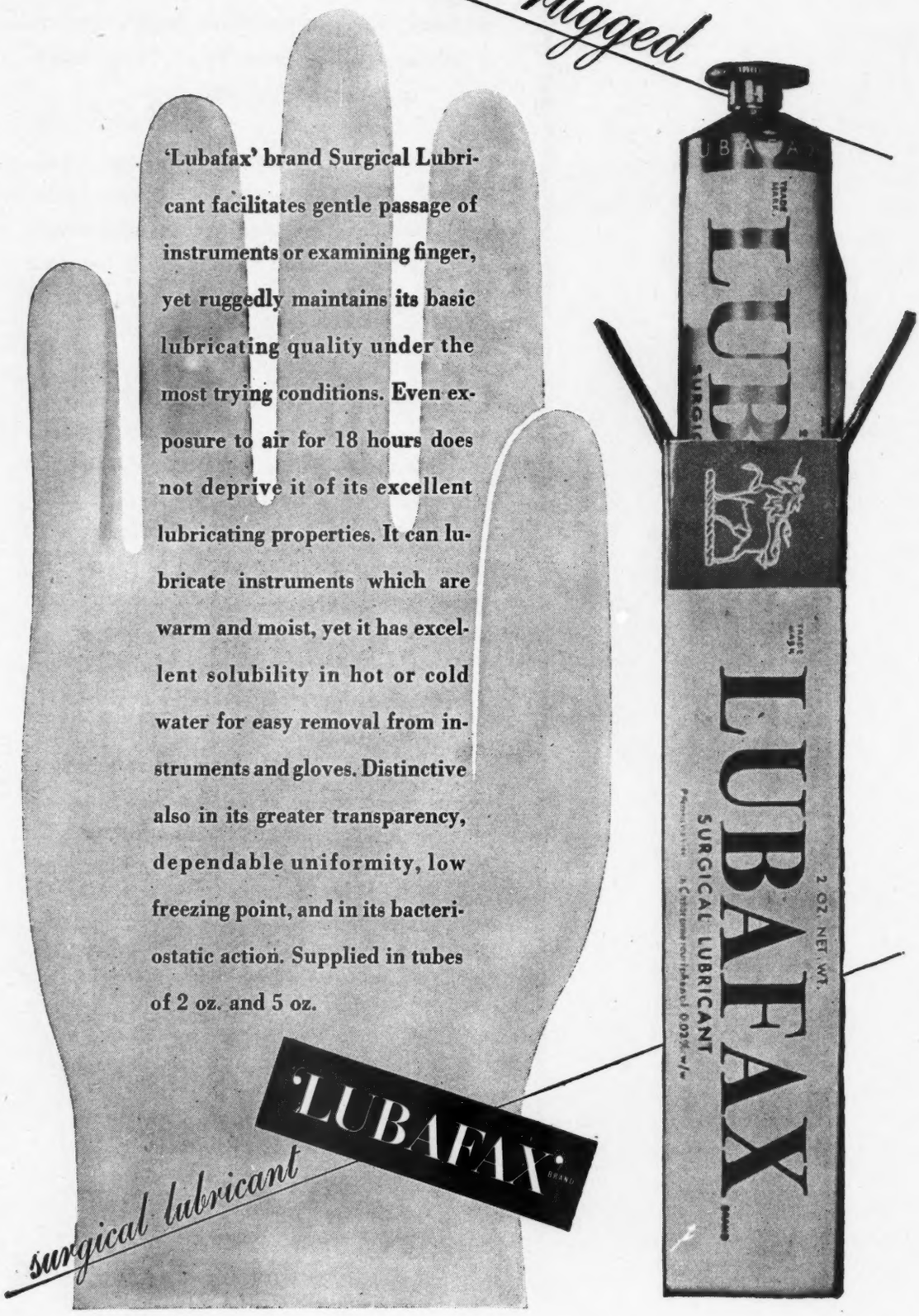
DARTHRONOL

A ROERIG PREPARATION

gentle but rugged



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Current practice is to employ oral penicillin in the treatment of less severe infections caused by the more penicillin-sensitive organisms, and where experience with parenteral therapy has shown that this antibiotic will not be required for prolonged and intensive therapy. Oral penicillin should be administered in a ratio of 5:1 to obtain blood levels comparable to those achieved with intramuscular injection.

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Iletin (Insulin, Lilly), U-20, U-40, U-80, and U-100, containing 20, 40, 80, and 100 units per cc., respectively.

Iletin (Insulin, Lilly) made from zinc-Insulin crystals, U-20, U-40, and U-80, containing 20, 40, and 80 units per cc., respectively.

Protamine, Zinc & Iletin (Insulin, Lilly), containing 400 and 800 units, labeled 40 and 80 units per cc., respectively.

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COURTESY, AMERICAN COLLEGE OF SURGEONS

Edward Martin

1859-1938

Surgeon, Organizer, Educator. Member of the Committee on Organization of the American College of Surgeons; President of the College's Clinical Congress; Clinical Professor of Surgery, Woman's Medical College of Pennsylvania, 1902; at the University of Pennsylvania Medical School served as Professor of Clinical Surgery, 1903-1910, and John Rhea Barton Professor of Surgery, 1910-1918; Member, Board of Managers, Swarthmore College, 1892-1938.

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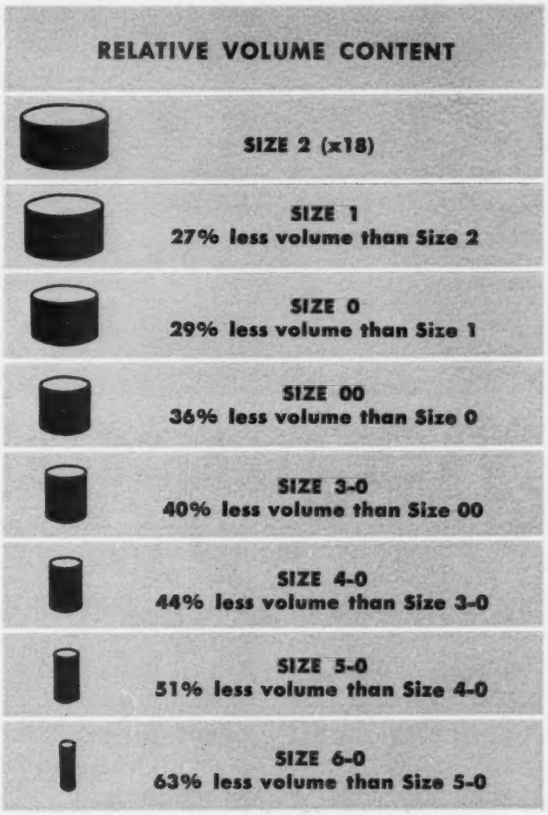

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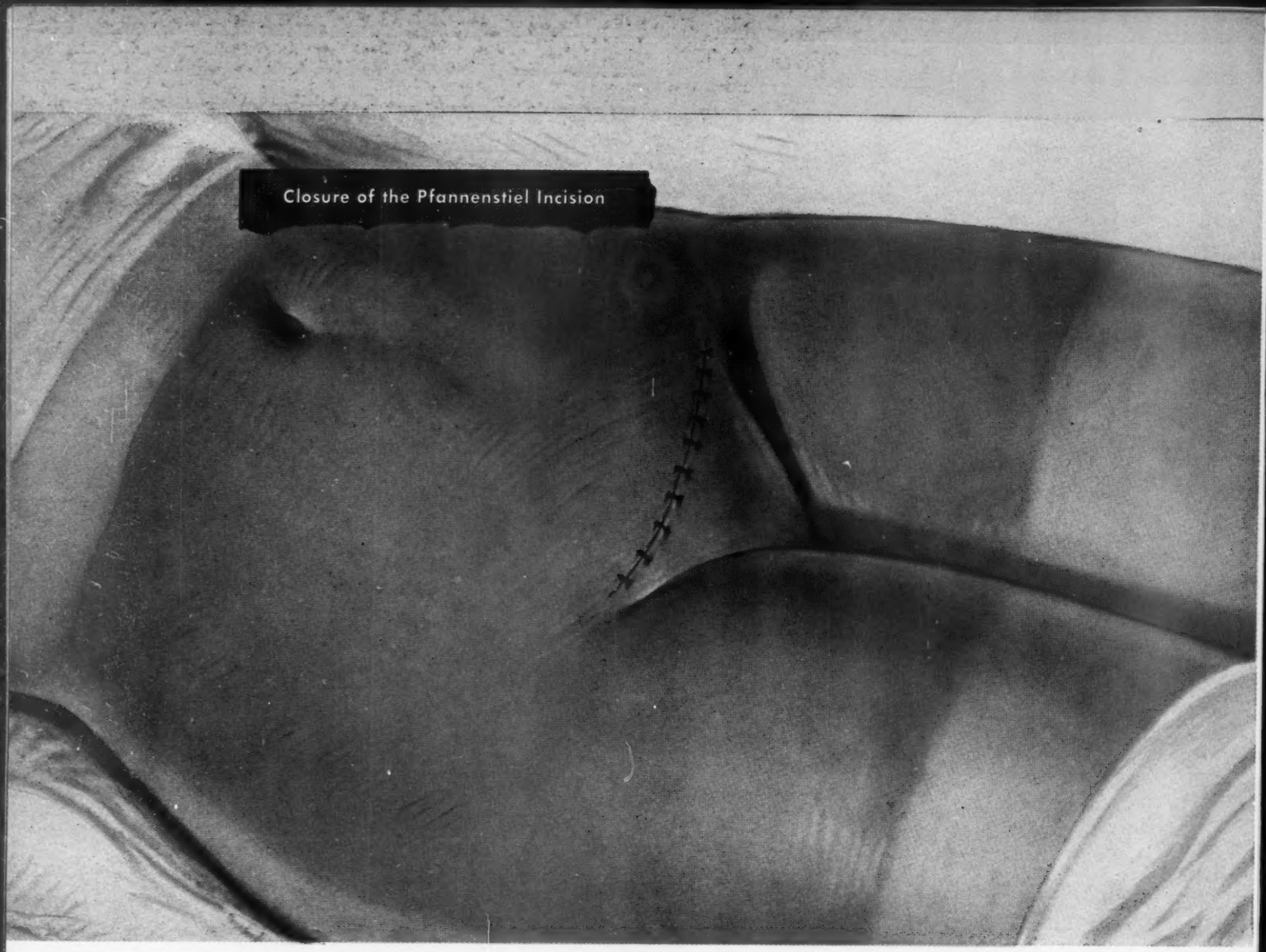

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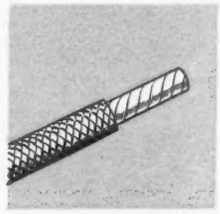

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The American Journal of Surgery

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A PRACTICAL JOURNAL BUILT ON MERIT

Fifty-fifth Year of Continuous Publication

VOL. LXXII SEPTEMBER, 1946 NUMBER THREE

Editorial

SURGERY IN WORLD WAR II

THE entrance of our country into a war of the extent of the recent conflict necessarily meant the marshalling of all our resources in order to bring the war to an early and successful conclusion. One of these resources was the medical profession, and not the least part of the profession consisted in those trained in surgery. The Medical Departments of the Army and Navy early recognized that they would need the services of thousands of men then in civilian practice. It was very fortunate that during the period between World War I and World War II, the advantages of and even the necessity for adequate training in surgery were recognized and encouraged.

Trained surgeons of all ages were in the armed services, and to this probably more than to anything else can be attributed the extraordinarily good results that were obtained in the treatment of war casualties. The value of trained personnel was never more apparent than in the military services. There were difficulties to be overcome, and one of these was the problem of rank; older or less well trained men with higher rank occasionally were, of necessity, called upon to work with younger men of more recent training. This difficulty was usually submerged in the general effort to accomplish the task to be done.

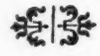
Only in a war of the magnitude of World War II is there an opportunity to study certain groups of cases on a large scale. The services are to be congratulated in their effort to segregate the various types of cases and to place them in charge of men whose interest and training made them of special value in the care of these patients. Not only were the patients able to receive more adequate care, but through the interest and diligence of many of the men caring for them, research problems were solved which will be valuable in civil life as well as in military surgery. The Medical Departments of the Army and Navy appreciated the value and necessity of selecting trained or promising young men and of giving them an opportunity to carry out research problems, even in the field.

In this review of war surgery, an effort has been made to cover fairly widely the field of surgery. Many of the papers are written by younger men, and all of them are first-hand accounts of actual work performed. Almost all the fields of combat are represented in this group, and the papers presented reflect experiences under various types of combat or continental positions. Each has to do with some form

of trauma or its treatment. No effort has been made to include in this symposium a review of other surgical conditions which arise as complications of diseases incidental to the war, such as those associated with malaria or amebiasis.

The editor wishes to thank the contributors to this symposium and to congratulate the publishers on their willingness to bring together a Review of War Surgery.

L. Kraeer Ferguson, M.D.



Every severely wounded person is shocked, especially if there is accompanying soft tissue damage and hemorrhage such as occurs with compound fractures. Shock should be anticipated and prevented as much as possible. When the patient is severely shocked, the general treatment must have precedence over local treatment.

From "Fractures and Dislocations for Practitioners" by Edwin O. Geckeler (The Williams & Wilkins Company).

Original Articles

THE SHOCK OF BATTLE WOUNDS

A REVIEW OF THE TREATMENT IN 2,000 CASUALTIES

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Cleveland Clinic
CLEVELAND, OHIO

DURING the first eight months of the campaign through France and Belgium, 10,700 wounded soldiers were operated upon in the 2nd Evacuation Hospital. More than 2,000 of these patients were treated for shock. This paper is a review of some phases of their preoperative treatment.

METHOD OF STUDY

Chart 1 is a sample of the chart completed on every patient who was admitted to the shock ward. Observations were made and recorded at least every thirty minutes. The chart accompanied the patient to the operating room where the anesthetist regularly recorded blood pressure, pulse and fluid intake, and to the ward where additional data could be added.

When the patient was discharged, the shock chart was extracted from the jacket and returned to us; subsequently our records on each shock chart were completed from retained clinical records by making an abstract of the patient's condition, course, operative findings and disposition.

An autopsy was performed upon all of the 251 patients who died, and the findings were added to the shock record.

Table 1 indicates the number of admissions the shock ward received each month. The patients have been classified according to the anatomical regions primarily involved. Although the majority of battle casualties suffer from multiple wounds, each patient has been listed only once, and under that region which encompassed his most severe injury.

CLASSIFICATION OF ADMISSIONS TO THE SHOCK WARD

It will be seen from Table 1 that the first subdivision is that of mild shock and severe shock. This subdivision is necessary because the treatment and results are widely different in the two groups. For statistical purposes, the patient was considered to be in severe shock if upon admission his blood pressure was below 100 systolic. If his blood pressure was above 100 systolic, he was considered to be in mild or compensated shock. It is recognized that impending circulatory failure due to a reduction of the effective blood volume is frequently masked by a compensatory vasoconstriction which maintains the blood pressure at a normal level despite the loss of a significant volume of blood.[1] Clinical judgment in appraising the true condition of a patient must, therefore, be influenced by other factors such as the severity of the wound, the probable amount of blood lost and by his general appearance and reactions. It would be a grave mistake to rely solely on the blood pressure in establishing the diagnosis of shock, and to treat only those patients in whom the compensatory mechanism has already failed. The subdivision of shock cases into mild and severe shock has been disregarded in the case of burns. As the location of the burns often rendered

CHART I

SAMPLE SHOCK SHEET

Date and Hour	Temperature	Pulse	Respiration	Blood Pressure	R. B. C.	Hemoglobin	W. B. C.	Hematocrit	Sp. G. Whole Blood	Sp. G. Plasma	Urine Output	Alert; Drowsy; Sleepy; Restless	Pain	Thirst	Sweating	Fluids in Cc.						Remarks
																P. O.	Blood	Plasma	Saline	Dext. 5% in Water	Dext. 5% in Saline	

OBSERVATIONS ON SHOCK

Number_____

Name_____

Age_____

Date and Time of Injury_____

Date and Time of Admission_____

Injury_____

Hemorrhage: Severe, Moderate, Mild

Type of Missile_____

Splints, Plasma, etc._____

the determination of blood pressure impracticable, severe burns were placed under the category of severe shock.

SIGNIFICANCE OF HYPERTENSION AND BRADYCARDIA AS OBSERVED IN SHOCK

An attempt was made to determine the significance and frequency of both hypertension and bradycardia in the presence of clinical shock. Hypertension was arbitrarily defined as a blood pressure exceeding 150/90 sometime during the course of treatment. It appeared in 233 or 10.3 per cent of the total admissions to the shock ward. Among the 251 patients who succumbed, nineteen or 7.6 per cent exhibited hypertension.

The frequency of hypertension suggests that it represented an overcompensation on the part of the arterioles in an attempt to maintain cardiac output in the presence of decreased circulating blood volume. Because of this, and because several such patients were passed through without treatment, only to suffer a sudden fall of blood pressure during the induction of anesthesia, we now consider hypertension compatable with shock and treat it accordingly. More often than not, the blood pressure returned to normal during the course of treatment.

The problem of bradycardia was found to be far more interesting as its relative frequency was unsuspected. The criteria chosen for the demonstration of bradycardia in the presence of severe shock were a pulse less than 90 with a systolic blood pressure less than 100. It appeared in 151 or 6.8 per cent of the patients admitted in severe shock, and in thirty-one or 12.4 per cent of the patients in shock who subsequently died.

No attempt to discover its etiology was made, although in two cases of cervical cord transection with bradycardia and shock there was a definite salutary response

TABLE I

NUMBER OF ADMISSIONS THE SHOCK WARD RECEIVED EACH MONTH

(Admissions have been classified according to the anatomical region primarily involved)

	July	Aug.	Sept.*	Oct.	Nov.	Dec.	Jan.	Feb.	Total
Mild Shock									
Brain	6	2		16	13	11	10	11	69
Maxillofacial	11	3		14	19	4	13	9	73
Spinal cord	1	1		0	1	1	0	3	7
Chest	9	5		18	24	12	12	7	87
Abdomen	8	1		6	12	9	5	2	43
Extremities	94	27		73	182	70	73	49	568
Skin (burns)	2	1		1	0	0	0	0	4
Severe Shock									
Brain	28	8		29	30	20	15	10	140
Maxillofacial	5	1		3	9	1	8	2	29
Spinal cord	0	2		9	8	2	3	1	25
Chest	22	10		23	40	27	25	11	158
Thoracoabdominal	9	6		16	7	8	14	3	63
Abdomen	10	3		25	20	24	36	16	134
Extremities	23	13		83	264	76	64	62	585
with gas gangrene	11	1		0	18	5	1	1	37
Skin (burns)	9	1		1	3	0	0	1	15
Total admissions	384	120		333	634	276	279	187	2213

* The hospital was inactive during the month of September.

Although there were 2,213 admissions to the shock ward during the eight-month period covered in this paper, the statistical data have been restricted to the first 2,000 charts.

of both blood pressure and pulse to atropine sulfate Gms. 0.0013 intravenously.

GENERAL METHODS OF SHOCK TREATMENT

The general treatment of shock is too well established to warrant routine comment. However, the necessity for a complete physical examination and for the redressing of all wounds must be stressed. Without these precautions, a sucking chest wound, crepitation and odor in an extremity wound, or evisceration in an abdominal wound may be overlooked. To be condemned is the occasional use of alcoholic beverages in the battalion aid station, as the vasodilation secondary to alcohol is distinctly prejudicial to shock.

FLUID REPLACEMENT

The most important factor in the treatment of shock is fluid replacement that is both quantitatively and qualitatively correct. In an evacuation hospital this must be determined to a great extent by clinical judgment, because the amount of laboratory work that can be done is limited. A discussion of the factors which determine the type and amount of fluid replacement is justified by the paramount importance of this phase of shock therapy.

Quantity. The amount of fluid required is determined by a combination of several factors: (1) General appearance and condition of the patient on admission, (2) estimated blood loss prior to admission; (3) amount of dehydration; and (4) estimation of expected blood loss in the operating room.[2]

In the presence of so many variables, there can be no inflexible rule for the volume of fluid required. We have found that it is more common to under-hydrate than to over-hydrate. The observations recorded on Table II indicate the relative

TABLE II

THE EFFECT PRODUCED BY A LARGE AMOUNT OF BLOOD, PLASMA AND CRYSTALLOIDS ADMINISTERED TO ONE PATIENT OVER A PERIOD OF TWENTY-FOUR HOURS

A private, thirty-four years old, was wounded four hours before admission to this hospital. His dressing had been changed at a medical collecting company because of fresh bleeding.

Diagnosis: Compound fracture of the left femur, tibia and fibula with destruction of the left knee joint.

Time in Hours	Fluids	BP	Pulse	Venous Pressure MM H_2O	Hematocrit	Specific Gravity Plasma	Total Protein	Urine Output, Cc.
0100		104/80	116					
0100–0300	1,000 cc. saline 500 cc. whole blood							
0300		120/72	136					
0300–1100	1,000 cc. whole blood 2,000 cc. dextrose 5% in saline 1,000 cc. dextrose 5% in water 750 cc. plasma							
1100		90/60	160	100	28	1.018	3.7	
1100–1200	1,000 cc. saline							
1200		90/50	148	140	28	1.018	3.7	
1200–1245	1,000 cc. dextrose 5% in water							250
1245		90/50	150	170	26	1.018	3.7	
1245–1500	2,000 cc. dextrose 5% in water							1,000
1500		90/50	140	120	25	1.017	3.4	
1500–1600	600 cc. whole blood							
1600		100/40	150	110	28	1.018	3.7	
1600–1700	750 cc. plasma							200
1700		120/50	130	118	30	1.019	4.4	
1700	Sent to operating room							
1700–0100	700 cc. whole blood							350
0100		110/70	96	112	40	1.022	5.4	

	Total Intake, Cc.	Total Output, Cc.
Whole blood	2,800	
Plasma	1,500	
Saline	2,000	
5% dextrose in saline	2,000	
5% dextrose in distilled water	4,000	
	12,300	1,800

The patient, a chronic alcoholic, belonged to blood group "A." Difficulty in obtaining compatible blood was encountered as cross-matching revealed his blood to be incompatible with stored group "O" blood. Improvement was maintained after operation, and the patient recovered.

safety of administering large amounts of fluid to a patient in severe shock, and show the effects produced by the fluids.

That the amount of blood required may be large is illustrated by one patient who suffered from an abdominal wound with a laceration of the inferior vena cava. He was given 7,500 cc. of whole blood preoperatively and during the operation. After ligation of the inferior vena cava the hemorrhage ceased and the patient made a good recovery. A full report of this case has been submitted for publication by Major Robert W. Fraser.

The blood pressure and pulse are valuable guides in determining the actual amount of fluid required only if they are constantly correlated with the patient's clinical condition. They cannot be relied upon exclusively for the following reasons:

(1) Bradycardia and hypertension have both been observed in the presence of clinical shock.

(2) In many instances a slight tachycardia and a normal blood pressure on admission do not indicate the fact that the patient is barely compensating for an extensive loss of blood (Case 1).

(3) A patient, whose extremities are cold and whose blood pressure and pulse are imperceptible on admission, may be restored to normal blood pressure and pulse with as little as 1,000 cc. of blood in one hour. It is obvious that a loss of more than one liter of fluid was required to produce hematogenic shock of such degree, and therefore unwise to assume that the fluid demands have been met as soon as the blood pressure and pulse return to normal.

(4) There is a small group of patients whose shock is apparently due to the absorption of toxins and not to fluid loss alone. In this group, it is illogical to expect that replacement of fluid will result in a return of the blood pressure to normal; therefore, it would be fallacious to use the blood pressure as a guide to the amount of fluid required.

(5) There are occasional patients who, despite a certain blood loss, would not be given a blood transfusion except that the possibility of extensive hemorrhage during operation makes it advantageous to start the operation with a full haemic component (Case 11).

CASE REPORTS

Case 1. A patient was admitted with a penetrating wound of the abdomen, a pulse of 120 and a blood pressure of 105/70. Despite the relatively normal blood pressure, the general appearance of the patient suggested acute blood loss, and a blood transfusion was started in each arm. One hour later his pulse was 112 and blood pressure 110/80. He was taken to the operating room, where, after being moved from a litter to the operating room table, he showed evidence of profound circulatory collapse. His pulse was 150 and his blood pressure was 80/50. He was perspiring and his respirations were rapid and labored. More blood was given rapidly and the operation started. It revealed a massive retroperitoneal hemorrhage which had been caused by a laceration of the external iliac vein. Despite the relatively normal blood pressure and pulse on admission, it is clear that the blood loss had been large but that active bleeding had ceased. When he was moved to the operating room, after the blood volume had been only partially restored with 1,000 cc. of blood in one hour, a clot was dislodged and bleeding recurred. A small additional loss of blood now quickly produced circulatory collapse. Blood pressure and pulse had been poor indications of the actual blood volume and the necessity for treatment.

Case 11. A patient was admitted with a tremendous foreign body in the chest cavity. His pulse was 84 and blood pressure was 140/100, and there was no evidence of massive hemothorax or air hunger. An *x*-ray revealed that the foreign body apparently extended into the hilus of the lung. Because hemorrhage following its removal seemed likely, the patient's blood was cross-matched and a transfusion of whole blood was started immediately preceding the operation. At operation, very brisk bleeding followed the removal of the shell fragment which had lacerated the main bronchial artery; the patient might have died had the operation been undertaken prior to the restoration of blood previously lost.

Type of Fluid. With the exception of burn cases, most surgical shock seen in war casualties is due to the rapid loss of whole blood. The almost invariable response to transfusions of whole blood indicates that there are few patients in whom this is not true. Hemoconcentration, although demonstrated in occasional instances, was seldom significant, and generalized fluid loss through permeable capillary endothelium did not seem to be important.[3] Therefore, the one essential therapeutic fluid is blood, and for it there is no real substitute.

As a supplement to the blood used, the choice lay essentially between plasma and one of the crystalloids, for albumin was not available.[4] With the exception of those instances in which there is a distinct indication for the use of plasma, one of the crystalloids is preferable for the following

reasons: (1) Serious reactions occasionally follow the use of plasma. Although we have had no fatalities from plasma, urticaria is not infrequent and temperatures to 108°F. measured per rectum have been produced. Serious reactions from the use of the crystalloids have not been observed. (2) Economy and ease of production of the crystalloid solutions; (3) ease of administration; and (4) the restorative effect of crystalloid infusions is scarcely distinguishable from results obtained with plasma, except in burns, and in the most severe types of shock.

In the treatment of mild or compensated shock we have used the crystalloids almost exclusively. As a supplement to whole blood, their importance in replacing the depleted extracellular fluid volume is unequivocal.

In actual practice we have completely ignored the original four plasma to one blood ratio rule as this introduces the cellular elements in too dilute a form. For the treatment of hematogenic shock, we have used plasma as a sustaining fluid while obtaining cross-matched blood, and occasionally as a hypertonic solution in the treatment of pulmonary edema or in the correction of hemoconcentration after the depleted extracellular fluid has been replaced by the crystalloids.

SURGICAL TREATMENT OF PATIENTS IN SHOCK

There is a significant number of patients who must receive surgical treatment while still in shock. These patients may be divided into four groups: (1) Those who without obvious reason fail to improve after adequate fluid replacement, (2) those who exhibit signs of respiratory obstruction; (3) those with uncontrolled hemorrhage; and (4) those with upset respiratory mechanics.

It soon became apparent that the optimum benefit from adequate fluid replacement could be observed within a maximum of five hours. If at the end of that time the patient had not recovered from shock, it was evident that whatever had produced the shock was perpetuating it, and that fluid replacement was not the complete answer to the problem. This was particularly true in the case of injuries to the extremities where gas gangrene, infection, muscle necrosis, and possibly subclinical infection of clostridial origin were constant threats and where waiting beyond a maximum of five hours might mean fatality.

With respect to respiratory upset, if the normal mechanism cannot be restored by conservative measures, and if fluid replacement has failed to increase the cardiac output in the presence of mechanically disturbed respiratory physiology, then corrective surgery offers the only solution and must not be postponed. Table III summarizes the results obtained on the patients subjected to surgery before shock had been controlled.

CAUSES OF FAILURE TO RESPOND TO SHOCK TREATMENT

The vast majority of patients respond dramatically to the transfusion of whole blood. Most frequently pulse and blood pressure, which were imperceptible on admission, were within normal limits after the first hour of treatment, and long before the fluid replacement was complete. If this expected response is not observed, the cause of the protraction of the shock must be sought immediately. It is largely the time factor in shock which permits decompensation to become irreversible. We have found that the most frequent causes of failure are: (1) Positive intrapeural pressure due to pneumothorax or hemothorax, or both, and usually associated with mediastinal shift; (2) acute gastric dilation; (3) unsplinted or inadequately splinted fractures, particularly those involving the knee joint; (4) exsanguination; (5) gas gangrene toxemia; and (6) probable toxic absorption from certain extremity wounds.[5,6]

Instances of toxic absorption most frequently follow injuries due to mine explosions, and are characterized by extensive muscle destruction and necrosis. Although

TABLE III

ANALYSIS OF THE NINETY PATIENTS WHO WERE SENT TO THE OPERATING ROOM IN SHOCK

Region	No. of Patients	Reason Sent to the Operating Room in Shock	No.	Survived	Died
Brain	9	(1) Extensive intracranial destruction with no response to prolonged treatment	7	2	5
		(2) Subdural hematoma	2	2	0
Spinal cord	1	(1) Hemorrhage from the external jugular vein	1	1	0
Chest	8	(1) Mechanical respiratory difficulty	6	3	3
		(2) Increasing hematoma of the neck	1	1	0
		(3) Hemorrhage	1	0	1
Thoracoabdominal	9	(1) Mechanical respiratory difficulty	4	0	4
		(2) Uncontrolled hemorrhage	5	4	1
Abdomen	18	(1) Uncontrolled hemorrhage	9	4	5
		(2) Intestinal perforation(s) with peritonitis	9	3	6
Extremities	45	(1) Suspected that shock was being protracted by the absorption of an unidentified toxin or factor	27	23	4
		(2) Uncontrolled hemorrhage	11	8	3
		(3) Gas gangrene toxemia	7	4	3
Totals	90		90	55	35

the toxin, if it exists, is unidentified, the behavior of these patients closely parallels that of the patient who is overwhelmed by the toxins of the gas producing organisms.

TRANSFUSION REACTIONS

Although an absolute necessity in shock therapy, the use of preserved group "O" blood introduces a cause of anxiety, namely that of transfusion reaction. In 6,003 whole blood transfusions given during the eight-month period covered in this paper, there were 101 severe reactions. There were four fatalities that we directly attributed to a transfusion reaction, and in three additional instances, we believed a transfusion reaction to be a contributing factor to the mortality. In twelve other instances, autopsy revealed evidence of gross kidney disorders that could not be directly attributed to trauma; we believe that hemoglobinuria in the presence of renal ischemia consequent to prolonged shock is a determining factor in the production of anuria, and have therefore included these patients as fatalities due to transfusion reaction.

Because of the danger associated with the use of group "O" blood, we have found the following precautions to be essential:

(1) If the patient exhibits a chill at any time during a transfusion, plasma or saline should be substituted for the blood until a cross-match can be performed. There are at present no criteria which will immediately differentiate a pyrogenic reaction from one due to minor incompatability. However, in occasional instances when it is believed that a forty-five-minute delay in whole blood replacement would be fatal, it becomes necessary to disregard the possibility of a reaction.

(2) If large amounts of blood are to be required (over 2,000 cc.) a certain amount of hemolysis is to be anticipated, and it is therefore advisable to perform a cross-match. In such cases, particularly if the patient belongs to any group but "O," we have started a blood transfusion immediately and at the same time cross-matched the patient's blood. The patient then receives only cross-matched blood after the first 1,000 cc. Despite this precaution some hemolysis of the recipient's cells due to incompatability in the minor match is to be expected. The actual amount of hemolysis produced varies directly with the rapidity with which the blood is introduced.

(3) If more blood is to be given to the same patient after a four to five-day interval, it is better to give cross-matched blood only. Also one now encounters the

TABLE IV
A SUMMARY OF THE DATA PERTINENT TO THE TRANSFUSION REACTIONS

Admissions to Shock Ward	Total Number of Blood Transfusions Given	
384	July	701
120	August	290
333	October	1080
634	November	1718
276	December	900
279	January	776
187	February	538
2213		6003

Total number of cross-matches performed—427
Total number of patients whose blood was incompatable with preserved blood—55
Total number of live donors used:
A—80 AB— 6
B—31 O—16

	Number	Per Cent of Total Transfusions	Hemoglobinuria
Severe reactions	101	1.6	21
Reactions apparently producing fatality	4	0.06	3
Reactions contributing to fatality	3	0.05	1
Renal disorders which may have been due to undetected transfusion reaction	12	0.19	2

Severe reactions according to groups (recorded in 83 per cent of the 101 reactions)
A—42 AB— 1
B—12 O—29
Total number of patients operated upon—10,700
Total mortality—326 or 3 per cent
Of the 326 deaths:
Reactions to transfusion apparently producing fatality—4 or 1.2 per cent
Reactions contributing to fatality—3 or 0.92 per cent

possibility of having produced anti-Rh antibodies (specific Rh positive agglutinins) in the serum of an Rh negative patient.[7] As there is no method available at the evacuation hospital level for detecting this, we have made the indications for transfusion after a four to five-day interval very rigid.

(4) Preserved group "O" blood should never be given as a tonic, and must be restricted to use as an emergency measure only.

Hemoglobinuric nephrosis is a constant threat, particularly when it is necessary to administer more then 2,000 cc. of preserved group "O" blood. Postoperative urinalyses have revealed twenty-seven examples of hemoglobinuria; there were undoubtedly others which passed undetected. In the prevention and treatment of the associated oliguria, we have been most impressed with the necessity for maintaining an adequate fluid balance. Routine alkalinization has seemed less important for the following reasons:

(1) A total of 6,003 blood transfusions have been given. Autopsies on the 251 fatal cases during this period of time have demonstrated only one instance of gross hematin precipitation. It is to be noted that although all patients did not receive alkaline therapy, the particular patient in whom gross hematin precipitation could be demonstrated had been alkalinized.

(2) If the primary lesion is assumed to be necrosis of the distal tubular cells and the precipitation of acid hematin a secondary and possibly unessential part of the syndrome, the alkalinization might be expected to be ineffective. Furthermore, if unexcreted, the large doses administered might produce sufficient alkalosis to decrease glomerular filtration.

The figures for the total number of transfusions given, the total number of patients treated on the shock ward and the total number of cross-matches performed have been included on Table IV. In the absence of this information, the total number of reactions is without significance.

Mortality Statistics. Table V has been compiled from autopsy reports, and although death was often due to a combination of factors, only the principal cause has been assigned in each case.

SUMMARY AND CONCLUSIONS

1. An evaluation of the treatment of 2,000 consecutive patients on the shock ward of an evacuation hospital is presented.

2. Hypertension, being an indication of vasoconstriction, is considered compatible

TABLE V

CAUSES OF DEATH IN PATIENTS TREATED FOR SHOCK

Brain	83
Cerebral destruction	69
Subdural hematoma	3
Meningitis	3
Pneumonia	2
Intracranial hemorrhage	1
Blast concussion	1
Cerebritis	1
Renal failure	1
Aspiration	1
Laceration longitudinal sinus	1
Maxillofacial	4
Shock	2
Anesthesia	1
Renal failure	1
Spinal cord	11
Respiratory paralysis	9
Peritonitis	1
Pneumonia	1
Chest	28
Intrapulmonary hemorrhage	9
Blast	5
Shock; hemorrhage	7
Pneumonia	3
Diaphragmatic hernia	1
Respiratory embarrassment	1
Renal failure	1
Blast lung and brain	1
Thoracoabdominal	29
Shock; hemorrhage	13
Peritonitis	6
Pneumonia	5
Tension pneumothorax	1
Intrapulmonary hemorrhage	1
Transfusion reaction	1
Renal failure	1
Diaphragmatic hernia	1
Abdomen	47
Peritonitis	18
Hemorrhage	11
Pneumonia	11
Intestinal obstruction	1
Renal failure	1
Retroperitoneal infection	1
Duodenal fistula	1
Extremity with gas gangrene	48
Gas gangrene toxemia	11
Shock; hemorrhage	9
Pneumonia	6
Shock	6
Shock; muscle necrosis	5
Anesthesia	3
Transfusion reaction	3
Gas gangrene antitoxin	2
Pulmonary embolus	1
Renal failure	1
Blood dyscrasia	1
Skin (burns)	1
Laryngeal edema	1

All patients who were treated on the shock ward and subsequently died, were included in the mortality statistics regardless of the cause of death and the postoperative day on which it occurred.

with the diagnosis of shock; it should not be regarded as proof that shock does not exist, nor as a contraindication to shock therapy.

3. Bradycardia in the presence of shock occurred more frequently than was anticipated. The dramatic response to intravenous atropine sulfate in two cases suggests that it may be due to vagal stimulation.

4. The qualitative and quantitative requirements for fluid replacement are considered, and the lack of close correlation between blood pressure, pulse and actual fluid requirement is pointed out. The primary importance of blood is stressed, and the indications for plasma and the crystalloids are discussed.

5. Indications for the surgical treatment of patients still in shock are given with results obtained.

6. The most common causes of failure to respond to adequate fluid replacement are outlined.

7. The problem of transfusion reactions and the clinical status of alkaline therapy are discussed.

8. Mortality statistics for all shock patients are included.

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A REVIEW OF THE BLOOD DONOR SERVICE OF THE AMERICAN RED CROSS

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DONATIONS of 13,326,242 pints of blood were made by approximately 6,660,000 voluntary donors from February 4, 1941, through August, 1945. Donors averaged two donations, approximately 1,500,000 gave three pints each, 150,000 gave a gallon and 3,000 gave two gallons or more. These volunteers provided the essential material, their blood, which made this gigantic project possible and at least 100,000 additional volunteer workers contributed unstintingly of their time and enthusiasm in countless ways to make this work a success.

The American Red Cross Blood Donor Service was inaugurated at the request of the Army and Navy as a joint undertaking of the American Red Cross and the National Research Council. The blood was donated to these services and was always at their disposal.

The service was expanded rapidly and at its height, donor centers were in operation in thirty-five cities, aided by sixty-five mobile units.

The National Research Council assumed responsibility for endorsing all technical and scientific procedures and the Red Cross all other responsibilities.

A National Director and a National Technical Director were appointed early and under their direction the same technics and methods were installed in all centers, giving an essential unification of the work everywhere. It is impossible to mention the many individuals who made major contributions to this many sided project. Only a few of the scientific studies have been published. The essential importance of work in recruiting donors, in the publicity field, in conducting the canteens, in many tiresome routine clerical and technical jobs cannot be properly realized except by those who had the privilege, through helping, of seeing these and many other phases of the work. In contrast to the large number of volunteer workers there were only 280 paid lay workers, 975 nurses, thirty-one doctors and approximately ninety-six doctors assigned from the Army and Naval Medical Corps. From the beginning there were two main objectives: to procure the amount of blood requested by the Armed Services and at the same time to take every precaution to protect and care for the donors. Not infrequently it was a difficult problem to persuade donors that they should not make a blood donation. This was especially true with many women who needed longer than the usual time to regenerate blood after a previous donation.

Careful and detailed regulations were formulated to govern all phases of the service—but they can only be given here in brief and abstract form. These include system of registration, age limits, physical requirements, care of donors before, during and immediately after bleeding, technic of vein puncture and bleeding, refrigeration, care of the bottles of blood and their rapid transfer to processing plants, etc. A complete report has been prepared by the National Director and will be released soon.

Donors between twenty-one and sixty years of age were accepted and also between eighteen and twenty with written consent of parents. Donors were requested not to eat a fatty meal and if possible to refrain from food for three to four hours before coming to the center. Careful and systematic questions were asked about present health and feeling of well being; recent illnesses, especially respiratory infections; malaria within fifteen years,

jaundice within six months, shortness of breath, asthma and definite allergic conditions, epilepsy, etc. A normal mouth temperature was required, and systolic blood pressure between 100 and 200 mg. of mercury and diastolic not above 110.

It was especially important to use a simple, rapid and accurate method for hemoglobin determination. It soon became evident that it was necessary, especially for women donors, to safeguard them by requiring a sufficient level of hemoglobin, in particular before repeat donations. After careful investigation of the literature and extensive consultation the minimal acceptable level was fixed at 12.3 Gm. of hemoglobin per 100 cc. of blood. The method used was an adaptation of the copper sulfate specific gravity method of R. A. Phillips and collaborators.* A single solution of copper sulfate of a specific gravity of 1.052 was used. If a drop of blood sinks immediately when dropped into this solution its specific gravity is greater than 1.052 and this indicates a hemoglobin content of 12.3 Gm. or more per 100 cc. of blood and the donor is acceptable. If the drop of blood does not sink immediately, the hemoglobin content is insufficient to allow a donation of blood. This simplified method was carefully checked by several comprehensive methods. Hundreds of volunteer workers learned to use this method quickly and accurately.

Whenever any question arose of suitability of a donor or inadvisability of a donation, for safeguarding the donor, the problem was referred to the physician in charge. He or she interviewed the donor, asked more searching questions when necessary and repeated any examinations when this was indicated.

All donors were required to drink a glass of water or of lemonade immediately before being bled. Each donor, after the blood donation, was accompanied by a volunteer worker to the canteen where coffee, tea, milk, soft drinks, crackers and cookies were provided. A nurse was in constant attendance to watch the donors during this rest period and to notice any tendency towards feeling ill or fainting. Rest on cots provided, in small rooms or cubicles, for the small percentage of donors who needed rest and observation or treatment. It was expected that some donors would faint and some fainted even before their donation or following the finger stick to obtain a drop of blood for hemoglobin determination. In a careful survey no serious effects or fatalities could be attributed directly to donation of blood. Fainting seemed to occur at times in waves; after one donor fainted others would unexpectedly do so. Also very occasionally bleeding would precipitate a spasm or even a general convulsion. These also, as far as is known, caused no serious after effects.[1]

The donors reclined on tables of operating room table height. After cleansing and sterilizing the skin over the veins at the bend of the elbow a drop of ½ per cent novocaine was injected intradermally over one vein. Vein puncture was therefore painless. Specially devised bleeding sets were used, each bottle containing 50 cc. of 4 per cent solution of trisodium citrate. The sets were sterilized by autoclaving each in a cloth bag. The blood entered the bottle by gravity, there being a protected air vent through the stopper of the bottle. The bottle was given a smooth, rotating movement at frequent intervals for mixing citrate solution and blood and preventing clots. After withdrawing the needle from the vein, a pilot test tube was filled with blood remaining in the rubber tube. This sample was used for serological and other tests.

The bottle of citrated blood was placed in a refrigerator immediately, and kept refrigerated in specially designed boxes during transmission to the processing plants, and there kept refrigerated during the entire process of separating the plasma from the cells. This separation was completed within seventy-two hours of the time the blood was obtained. The processing was carried out at about ten commercial

* Boynton, M. H. The use of the copper sulfate method of hemoglobin estimation for screening blood donors. *J. Lab. & Clin. Med.*, 31: 40, 1946.

laboratories throughout the country, and under contracts with the Army and Navy. Representatives of the Biologics Division of the National Institute of Health supervised and controlled this part of the work. The laboratories expanded their plants and increased and trained their personnel with astonishing rapidity. They also gave cooperation of a high order not only with the American Red Cross and the Services but also with one another, sharing information of methods, technics and general "know how." This is evidenced in a concrete manner by an extremely low percentage of loss from breakage, contamination, etc.

Serological tests for syphilis were performed on each sample. Only serologically negative plasmas were pooled. Pools were made of the plasma from twenty-five or more bottles, and immediately distributed into the final containers. At first 300 cc. of citrated plasma and after a short interval 500 cc. were placed in each bottle. Immediately afterwards, the plasma was shell frozen in each bottle, at about minus 70°C., and stored at about minus 20°C. As soon as bacteriological control tests of the liquid pools released them, the plasma was dried from the frozen state with the aid of a high vacuum and careful temperature control to prevent thawing during the drying process. Small pilot samples of frozen plasma were also dried and cultured before the final dried product was released. The dried plasma was porous, uniform in appearance and cream colored or light yellow in color. It rapidly dissolved, i.e., in one to five minutes, when pyrogen free distilled water containing a small fraction of a per cent of citric acid was added.

Each bottle of plasma was put in a tin can and hermetically sealed. Another bottle containing the volume of distilled water necessary to restore the dried plasma to its original volume was also packed in a similar tin can. These two, with directions for rejuvenation and use, with needles for mixing and a sterile, expendable intravenous infusion set (including filter) were packed in a strong paste board carton. Groups of eight or ten of these were then packed in larger cartons and delivered to the Army or Navy. The Services had on hand not only their necessary quotas but a reserve for any emergency requirements. As is well known an ample supply of plasma was distributed to our forces all over the globe, to all ships, airports, hospitals and even to front lines and invasion beaches.

While this work was going on E. J. Cohn[2] and his group perfected and developed remarkable methods for fractionating plasma into a number of important fractions including liquid, serum albumin for the intravenous treatment of shock, Gamma globulin, useful in prophylaxis of measles, infectious hepatitis and perhaps other diseases; thromboplastin for controlling hemorrhage, either alone or when combined with fibrin foam, fibrin films for covering brain areas at operation and minimizing or preventing adhesions; and iso-agglutinins of blood groups A and B for blood grouping tests. This does not include the entire list and the publications of this group can be consulted for complete reports and for details. For these important products a large amount of plasma was diverted to the pilot plant of the Harvard group of investigators and to a number of processing plants. The supply of plasma permitted this without interfering with the dried plasma supply to the Services.

For a while no large scale use could be made of the cell residue after the plasma was withdrawn. There had been small reports of use of resuspended cells for transfusion where the patients need was for cells, and oxygen carrying power and not for whole blood, as in chronic anemias, leukemias, etc. In Detroit, W. B. Cooksey[3] made the first large use of resuspended cells for these purposes. The packed cells were resuspended in physiological saline solution and had to be transfused not longer than five days after they were drawn. They were used in local service and civilian hospitals in large amounts with excellent results. Only Group O cells were distributed to simplify their use and to avoid mistakes of using incompatible cells. Later a similar project was instituted in

New York City. After awhile it was found that a solution of 10 per cent corn syrup in distilled water could be used for resuspending the cells and would increase the safe period of storage before transfusion to fourteen days.[4] This gave greater leeway to use in hospitals and 9,000 transfusions were performed in about twenty service and civilian hospitals with cells suspended in 10 per cent corn syrup. They were used with beneficial results and without any deleterious effects.

Another use for red cell residues was found by M. M. Strumia[5] and his group. They prepared a purified globin solution which they found useful in treating shock, acting in somewhat the same manner as a 25 per cent solution of serum albumin.

At the termination of the war stocks of some of the products described remained on hand. Some of these are being distributed for civilian use, so that many civilians who donated blood are directly benefiting by their wartime generosity. Considerable amounts of the gamma globulin fraction has been distributed on a nation wide basis through health departments for ameliorating or preventing measles in children who have been directly exposed to infection with this disease. Similarly, large amounts of dried plasma have been distributed to hospitals for civilian use. Some of the other products have also been available.

It was recognized early that adequate treatment of hemorrhage and shock due to hemorrhage, required immediate transfusion of whole blood. Blood banks had been set up in the European theatre of operations, but while they functioned well, their facilities were inadequate.

Accordingly, in August, 1944, at the request of the Surgeon Generals of the Army and Navy, a project for the procurement of whole blood in the continental United States and its shipment to the various combat zones was jointly undertaken by the Army and Navy in cooperation with the Red Cross Blood Donor Service. Plans had been in readiness for this request and had been formulated by the Department of Surgical Physiology of the Army Medical School[6] and the Plasma Laboratory of the Naval Medical School. The technics used were based on the liquid plasma program of the Army and Navy.[7]

The procurement, collection, preservation and shipment of whole blood presented problems of a different technical nature than those of the dried plasma program. Since the whole blood was destined for use in combat zones, it was anticipated that no compatibility tests could be made at the time of transfusion. Only group O blood, the so-called "universal donor" blood, could be of value, as properly prepared group O requires no cross-matching before administration and can be given to recipients of any blood group without danger.

Procurement. Whole blood laboratories were set up in already existing Red Cross Blood Donor Centers in twelve cities. Previously, it had been unnecessary to perform blood groupings on the donors for the plasma program. To avoid doing complete blood groupings, all donors were screened for group O only. At the time the hemoglobin content was being determined, a drop of the donor's blood was placed in a small vial of normal saline. A few drops of this cell suspension were then placed in another vial containing dried group O serum. This serum was specially prepared and had both a high anti A and anti B agglutinin titer and a high avidity index. After ten to fifteen minutes, while other routine tests were taken of the donor, the vial was examined. The absence of agglutination denoted on O donor, while its presence signified that the donor was not group O. The O donors were bled by a special technic while those who were not group O were handled in the usual manner. In this way, bleedings for whole blood and for plasma took place in the same bleeding room and the selection was made without any disturbance of routine or loss of time.

Collection. The original container into which the donor was bled would also be the container at the time of the actual transfusion. Accordingly, the closed system vacuum, technic was adopted because it afforded the optimum protection against

bacterial contamination. In addition, with this system and with special attention to the preparation and cleaning of tubing and needles, pyrogen contamination could be eliminated. The nursing personnel who performed the actual phlebotomies were specially trained in these technics. It is worthy of note that due to the ability and conscientiousness of these nurses, reports from the field revealed an unprecedented low rate of reactions.

Preservation. To be of practical value, the solution used to preserve whole blood destined for overseas use must of necessity adequately preserve the red cells for a minimum of fourteen days. At the time the whole blood program began, Alsever's solution was the best available and was used during the first few months. This was a very adequate preserving solution, but because of its bulk—500 cc. of fluid to 500 cc. of blood—was somewhat unsatisfactory. On the basis of experimental work done by the Sub-committee on Blood Substitutes of the National Research Council, the Loutit-Mollison ACD solution was later substituted for the Alsever's solution. ACD solution is a mixture of sodium citrate, citric acid and dextrose. It has the advantage of requiring only 120 cc. of fluid to 480 cc. of blood. This solution proved quite satisfactory and maintained the red cells in a good state of preservation for a minimum of twenty-one days, based on cell survival studies, rate of hemolysis and potassium content. An expiration date of twenty-one days after the date of collection was placed on the label of each bottle shipped overseas.

Refrigeration. Regardless of the preserving solution used, the degree of preservation of red cells is in direct proportion to the constant maintenance of refrigeration of the blood at temperatures ranging from 4° to 6°C. Temperatures lower or higher than these cause excessive hemolysis. Considerable efforts were made to maintain this temperature range. All bleeding bottles were pre-cooled to 4°C. before use. As soon as possible after collection the blood was placed in refrigerators constantly maintained by a thermostat at the proper temperature. Before facilities were available, the blood was shipped overseas in insulated containers and as soon as it reached its destination was placed in a refrigerator. Shortly after the start of the program, an expendable refrigerator using wet ice was developed which would maintain a temperature range for forty-eight hours of 5°C. to 10°C. while en route. Facilities were available for re-icing while in transit. While these temperature ranges were not ideal, nevertheless, the expendable refrigerator was a very practical factor in preserving the blood during shipment. This was of considerable importance since the blood was transported distances ranging from 3,000 to 8,000 miles from the collection point to the site of transfusion.

Testing. Each bottle of blood was immediately sent to the laboratory after collection, together with a pilot tube of 8 to 10 cc. of blood which were drained from the tubing of the bleeding set. The bottle of blood was placed in the refrigerator while the pilot tube of blood was used for the various tests. These included a proof typing for group O, a Kahn test, Rh testing and an agglutinin titration. Since as many as 1,500 pints of blood were processed in one laboratory daily, these tests were set up on a mass production basis. However, accuracy was not sacrificed for speed, as a check system proved the reliability of all tests.

(a) *Proof Blood Grouping.* The most important single test performed was that of the proof grouping for group O. The O bloods had been tentatively identified on the basis of the screening test. Before a bottle of blood was certified as O and shipped as such, it was proved to be so, since it was essential that only O blood be used, as blood other than O could cause a serious or fatal transfusion reaction if administered to an incompatible recipient. The test for proof grouping of O blood is based on the fact that the serum of group O blood contains both anti A and anti B agglutinins. If either or both of these are

not present in a serum, the blood cannot be group O. Hence, before a blood can be shipped as O, the presence in its serum of both anti A and anti B agglutinins must be determined. Anti A agglutinins are detected by testing the serum with known A cells, anti B agglutinins by testing with known B cells. If agglutination does not occur in both instances, the blood is not group O. Such non O blood was not sent overseas but was used in local military hospitals. The success of the screening test was well demonstrated by the fact that in over 380,000 such tests the error in grouping was 0.5 per cent.

(*b*) *Kahn Test.* The standard three-tube Kahn test was performed routinely on all blood specimens. All doubtful or positive Kahns were checked with the Wassermann test. Bloods with positive Kahns or with doubtful Kahns confirmed by the Wassermann test were discarded. The combined incidence of doubtful and positive Kahns amounted to 0.4 per cent.

(*c*) *Rh Testing.* It was known that Rh negative recipients may develop Rh antibodies if transfused with Rh positive blood, particularly if multiple transfusions were given. Since multiple transfusions for the treatment of severe casualties were the rule rather than the exception, it was necessary to provide Rh negative recipients with Rh negative blood. Accordingly Rh testing was performed by the technic as described elsewhere[8] and a quantity of Rh negative blood specifically labelled as such was shipped each day.

(*d*) *Agglutinin Titration.* As already stated, properly prepared group O blood can be given to recipients of any blood group without reaction. This means group O blood with a low agglutinin titer. Group O blood contains both anti A and anti B agglutinins. It is theoretically possible that such agglutinins can cause destruction of A, B and AB cells. Practically, it was believed that this occurs only when the titer of these agglutinins is over 1–600 by the tube centrifuge technic. Accordingly titrations for anti A and anti B agglutinins were performed on every serum by a method detailed previously. A titer of 1–600 was chosen as the arbitrary dividing line. Those bloods with titers under 1–600 were shipped as "universal donor" blood and those with titers over 1–600 were specifically marked: "This blood contains a high titer of anti A and/or anti B agglutinins and should be given only to an O recipient." Recent work, however, indicates that a titer of 1–200 by the tube centrifuge technic would be a safer point at which to separate high and low agglutinin content.[9]

Witebsky and his associates[10] have for some time advocated the routine addition of A and B specific substances to group O blood in order to neutralize the anti A and anti B agglutinins. Recent experimental work has corroborated their findings to the extent that the use of A and B specific substances to prepare O blood as universal donor blood is now recommended for military purposes.[11] However, their use to condition O blood for transfusions to women of the childbearing age is potentially harmful.

Checking and Packing of Blood. In addition to the various laboratory tests performed, a comprehensive system was developed of checking the numbers on the blood bottle and pilot tube to insure that no clerical errors were made. Each blood was kept in the refrigerator at 4°C. until ready for final shipment. Before being packed in the expendable refrigerators, the blood was carefully checked for short collections (less than 350 cc.), excessive hemolysis or fat, and the presence of clots. All bloods with any of the foregoing were discarded as well as those with a positive Kahn. In addition, bloods which were not group O were removed for use in local military hospitals. All Rh negative and high agglutinin titer bloods were checked to insure their proper labelling.

Just prior to shipment the bloods were packed in the previously iced expendable refrigerators. Twenty-four bottles, each containing a pint of whole blood, were packed in each box. In addition, twenty-four sterile pyrogen free intravenous sets

with filters, packed in a vacuum sealed can were shipped in the cover of each box. The set was completely adequate for performing a transfusion. These sets were expendable and were intended for use only once. The use of these sets contributed in great part to the low reaction rate that resulted from these transfusions.

Shipping. All whole blood was shipped by air. Shipments to the European theatre were handled by the Army Air Transport Command and those for the Pacific by the Naval Air Transport Service. The highest priority was given these shipments. A maximum of twenty-four hours elapsed between the time of collection and the take off by plane. Both air Services gave the fullest cooperation. Facilities for re-icing and the checking and storage of blood if delayed, were available throughout the route. Both theatres of operations had worked out an extensive distributing system so that blood was often being transfused at the front lines forty-eight hours after its collection.

Results. It is obviously impossible to determine scientifically and accurately the reaction rate of transfusions administered under combat conditions. However, on the basis of official reports, eye witness accounts and the related experiences of hundreds of Army and Navy physicians, it may be conservatively stated that the results of the use of whole blood shipped from the United States were most beneficial and that the reaction rate at least approximated those prevailing in the best civilian hospitals in this country.

Some 380,000 pints of whole blood were procured, processed and shipped in the manner described and with the excellent results as noted. Such a system with minor modifications can easily be adapted to large scale operations of civilian blood banks. A few such banks are already successfully operating. Plans are now in the developmental stage for the opening of large community blood banks to supplement the present inadequate facilities for supplying whole blood to civilian hospitals.

It was realized during the wartime development of the blood donor service, that it offered a large scale opportunity for various observations and investigations and this opportunity might never recur. Advantage of this was taken therefore by many individuals and groups to pursue studies of various types. Reports of some of these have been published and undoubtedly others will be published in the near future. The entire project was a demonstration of collaboration and cooperation of huge numbers of people, from all walks of life and of a variety of skills and professions, to aid the war effort, to save the lives of our servicemen and to advance the art and science of medicine.

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THE USE OF BLOOD AND PLASMA IN THE TREATMENT OF BATTLE CASUALTIES

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AN accurate assessment of all therapeutic advances introduced into military surgery during the past few years is not as yet possible. It is certain, however, that one of the principal factors which contributed to a lessening of the mortality of battle casualties in the recent war was the availability of whole blood and plasma. Transfusions were frequently solely responsible for the successful evacuation of wounded soldiers to medical installations where definitive care was available. Similarly, in vast numbers of cases, extensive surgical procedures were feasible only through the agency of transfusion therapy, which compensated for further blood losses incurred during operation and which was required for the provision of adequate supportive care postoperatively.

Long prior to the war it was generally recognized that one of the prime considerations in the prevention and treatment of traumatic shock is the restoration of the blood volume. Accordingly, as a preliminary step in equipping the armed forces to combat shock, the Medical Corps of the U. S. Army and Navy was supplied with large quantities of dried pooled human plasma derived from blood donated by civilian volunteers. Plasma proved to be an adequate blood substitute for the correction of oligemia. Moreover, its stability over a wide temperature range obviated difficult storage and distribution problems; it could be packaged conveniently and administered with relative safety to recipients, irrespective of their blood groups, thereby eliminating the need for time-consuming compatibility tests. These were highly estimable qualities, particularly from a military point of view, and it was anticipated that, in most cases, the transfusion requirements of the armed forces could be fulfilled amply by the sole use of plasma. The necessity for providing whole blood on a large scale was not seriously considered until it became evident, through practical combat experience, that the treatment of casualties who had sustained severe hemorrhages must include, not only the correction of a depleted blood volume, but also the maintenance of an adequate blood oxygen capacity. In order to meet this requirement, approximately eighteen months before the end of the war, adequate equipment became available for the venesection of local donors and for blood transfusion; most important, blood banks, organized in the various theaters of operation as well as in the United States, proceeded to effect an extensive and continuous distribution of stored whole blood to medical installations operating in combat areas.

THE RÔLE OF PLASMA IN WAR SURGERY

As the indications for the use of whole blood became increasingly clear, and with adequate facilities available for obtaining whole blood, the use of plasma began to assume a relatively subsidiary rôle in transfusion therapy. It nevertheless continued to be the mainstay of emergency shock treatment. In contrast to whole blood, plasma could always be supplied in adequate quantities, and in a satisfactory state of preservation, to the most advanced echelons of the Medical Corps. Through its

use an increase in blood volume could be effected with a minimum of delay, danger and technical difficulty, and for these reasons it proved to be of incalculable value in the prevention and correction of circulatory failure in recently wounded combat casualties, prior to their evacuation and the inception of their definitive treatment. Excepting in cases with serious wound hemorrhage and operative blood loss, the replacement therapy with plasma alone adequately sufficed; furthermore, in the resuscitation of patients following severe hemorrhage, it served to augment the volume of transfused protein fluid, thereby conserving the relatively limited supplies of whole blood. Plasma was also widely used for nutritional purposes, inasmuch as it was the only source of utilizable protein available which was suitable for intravenous injection. Finally, wisely or unwisely, plasma transfusions were employed as the chief form of replacement therapy in the treatment of burns.

The prime defect of plasma as a transfusion medium is, of course, its inability to transport oxygen, which limited its usefulness to an important extent. Circulatory collapse following severe hemorrhage could be averted by the use of plasma, but at the cost of producing, by erythrodilution, an anemia which could be extremely severe, depending on the total residual red cell volume and the amount of plasma injected. The complication of anemia proved to be a serious consideration from several points of view. It greatly jeopardized the prognosis of casualties who required extensive surgical procedures which involved general anesthesia and were attended by further blood loss. Its presence was especially deleterious in patients with chest wounds who suffered from impaired pulmonary ventilation and resultant anoxemia. The correction of this anemia, moreover, was a difficult therapeutic problem; for the preparation of concentrated red cell mixtures for transfusion was not feasible, and the more nearly complete a restoration of blood volume had been accomplished through the use of plasma, the more nearly impossible became the task of increasing the red cell concentration by whole blood transfusions. A serious and common dilemma was presented by patients who, in addition to perforating chest wounds with intrapulmonary hemorrhage, had sustained a massive blood loss and whose blood volumes had been substantially restored by plasma infusion. This type of patient, severely anemic, but with a relatively normal blood volume, anoxemic as a result of pulmonary damage, and possibly requiring early surgery with general anesthesia, posed an extremely grave operative risk. Although demanding an optimal red cell concentration in view of the anoxemia, and with general anesthesia and further blood loss in prospect, blood transfusion at this stage was a precarious procedure, prone to enhance the pulmonary hemorrhage and to precipitate pulmonary edema.

The unrestricted use of plasma, unsupplemented by whole blood, thus proved to be a dangerous practice in the preliminary management of wound shock. As a result of practical experience, the policy eventually adopted was to use the minimum amount of this material that was required to maintain a level of arterial pressure consistent with safety, and to institute whole blood therapy as promptly as possible. For the prevention of "irreversible shock" the essence of treatment was not only the early correction of oligemia and hypotension, but the avoidance and treatment of severe anemia.

TRANSFUSION REQUIREMENTS IN THE TREATMENT OF WAR WOUNDS

The magnitude of the blood loss incurred as a result of various types of battle injuries was substantially greater than had been generally envisioned. This fact early became evident through deduction from the severity of anemia which commonly followed restoration of the blood volume to normal, either through spontaneous hemodilution or as a result of plasma

transfusion. Actual measurement of the blood volume in traumatic cases, carried out by several observers[1,2,3] indicated that a reduction of as much as one-half of the normal blood volume, or 2,000 to 3,000 cc., was by no means a rarity, and that losses of between 1,000 and 2,000 cc. were not uncommon in seriously wounded soldiers. The severest hemorrhage was produced most consistently by extremity wounds, especially by traumatic amputations, and as a result of perforating wounds of the abdomen. It is noteworthy, moreover, that the average operative blood loss attending the surgical repair of perforating abdominal wounds was exceeded only by that accompanying extensive débridement of extremity wounds. The losses in these two types of procedures were frequently as great as 1,000 cc., and occasionally in excess of 3,000 cc.

Overall statistical data relative to the amounts of blood and plasma utilized in the treatment of battle casualties are not particularly illuminating, excepting as they pertain to the problems of procurement and supply. The magnitude of the volumes required for the early replacement therapy of non-transportable casualties due to abdominal, chest or severe extremity wounds are well illustrated, however, by the results of a survey conducted at the time of the Normandy campaign. In this it was found that the average volume of blood and plasma received by casualties admitted to Field Hospitals, estimated from the time of injury through the first postoperative day, was approximately 2,500 cc., of which blood and plasma comprised approximately equal amounts. Later in the course of the European war, when adequate supplies were ample to meet all requirements, relatively more whole blood was used in proportion to plasma.

The clinical criteria regarded as important in the regulation of transfusion therapy were by no means standardized, and there was little uniformity in their application throughout the Medical Corps. However, despite a considerable variation in resuscitation procedures and transfusion policies, as carried out by individual surgeons and separate hospital units, there gradually emerged certain concepts pertaining to the therapeutic indications for the use of blood and plasma, the validity of which became generally accepted. It was recognized, for example, that certain types of wounds and operative procedures are almost invariably accompanied by a significant blood loss, which in large measure accounted for their "shocking" character.

Of all the clinical signs and symptoms indicative of blood volume deficiency, the most reliable, in practice, proved to be the level of the arterial blood pressure. It was well known, however, that this sign is helpful only if grossly abnormal, and that a significant degree of oligemia may exist in the absence of hypotension, as long as the patient is in a horizontal position. It has been demonstrated that a blood volume deficiency of as much as 1,000 cc. frequently is not reflected by hypotension, a normal, or even an elevated, arterial tension being maintained through compensatory vasoconstriction until possibly the patient is subjected to general anesthesia or to further blood loss during operation, when the blood pressure may precipitously decline. Thus, casualties with wounds suggesting the possibility of significant hemorrhage were customarily given transfusions in the course of their preoperative preparation, notwithstanding a normal arterial pressure. By the same token, the transfusion of patients treated for severe shock was not discontinued promptly upon restoration of a normal pressure, but, unless specifically contraindicated, an additional amount was supplied on the assumption that there probably still existed a blood volume deficit of between 500 and 1,000 cc.

The presence of sustained hypotension in recently wounded battle casualties was accepted as evidence of severe oligemia and transfusion therapy applied accordingly. Blood volume measurements have shown that the blood volume deficit in cases of

this type, with systolic pressures less than 85 mm. of mercury, almost always exceeds 1,200 cc.[1] Unfortunately, from the standpoint of simplified therapeutics, hypotension is also a feature of severe infection, uncomplicated by oligemia, and may frequently be a deceptive finding in patients with perforating abdominal wounds and peritonitis. This type of shock, of course, is not improved by transfusion, despite which these patients occasionally received excessive amounts of blood and plasma on the erroneous assumption that the circulatory failure was attributable to an inadequate blood volume. Hypotension, in the absence of oligemia, is likewise commonly associated with prolonged anoxemia and central nervous system injuries, and was therefore occasionally responsible for injudicious management in patients with wounds involving the lungs, brain and spinal cord.

Certain other clinical signs, although in general less reliable than the blood pressure as indices of blood volume deficiency, proved of some value in the regulation of transfusion therapy. The trend of the pulse rate, the temperature and color of the skin, and the degree of venous distention occasionally provided confirmatory evidence, either of adequate response to treatment or of progressive circulatory failure. These circulatory manifestations, however, were subject to numerous influences having no bearing on the transfusion requirements, such as prior exposure to heat or cold, the temperature of the immediate environment, pain, the emotional status of the patient, or physiological disturbances arising as a result of anoxia or infection. The degree of anemia and hypoproteinemia were useful only to a limited extent within the first few hours after injury, so slow is the progress of spontaneous hemodilution following hemorrhage. However, the finding of any degree of anemia within a few hours after injury in a casualty who had received no plasma, or the discovery of anemia that was disproportionally marked in consideration of the amount of plasma that had been transfused, provided strong confirmatory evidence of significant blood loss.

COMPLICATIONS OF TRANSFUSION THERAPY

Excessive Transfusion. The use of excessive volumes of blood and plasma, resulting in pulmonary congestion and edema, was a fault most likely to occur in treating patients who exhibited a low arterial pressure from causes other than oligemia, such as peritonitis, anoxemia, and sympathetic nervous system paralysis following head or cord injuries. This therapeutic error appeared to be especially hazardous when it occurred during the course of general anesthesia. Unusual caution was necessary in treating patients with severe oligemia who had been in shock for many hours. In cases of this type, not only was there an increased susceptibility to the development of pulmonary edema with restoration of the blood volume but, because the arterial pressure responded sluggishly or failed to respond to transfusion therapy, one was tempted to carry this procedure to excess, on the basis of a mistaken diagnosis of continued bleeding. Excessive transfusion was extremely dangerous in patients with perforating wounds of the chest and intrapulmonary hemorrhage because of the possible production of increased bleeding and pulmonary edema. Ideally, in these cases, whole blood was employed, unsupplemented, if possible, by plasma; it was given slowly, and the amount injected limited to the minimum required to maintain an arterial pressure of approximately 100 mm. of mercury.

Pyrogenic Transfusion Reactions. Chills and fever, developing within an hour following the infusion, occurred as a complication of at least 2 per cent of blood transfusions. These reactions were frequently accompanied by a fall in arterial pressure. Although inherently benign, they were to be feared in extremely ill patients

already on the verge of circulatory collapse, and without doubt were immediately responsible for a small proportion of fatalities. The incidence of pyrogenic reactions was relatively high in medical installations employing locally prepared transfusion equipment, presumably as a result of inadequate cleansing and sterilization of tubing and glassware. The common technical faults in the preparation of equipment were failure to utilize an effective detergent, such as trisodium phosphate, to insure immaculate mechanical cleansing, and failure to carry out sterilization promptly after cleaning, thereby favoring the growth of air-borne contaminants, which, despite subsequent autoclaving, remain pyrogenic.

A similar type of reaction followed the injection of stored blood, partially hemolyzed as a result of inadequate or interrupted refrigeration during prolonged storage. Hemolysis appeared to be promoted by the settling and packing of red cells, which, sequestered at the bottom of the flask, were isolated from the preservative diluent. It was noted that cellular packing occurred most readily in elongated bottles which were constricted in the midportion; avoidance of the phenomenon depended upon periodic resuspension of the cells by mechanical shaking or by daily inversion of the bottle. Cell-free hemoglobin solution, from which the stroma had been completely removed, did not appear to have pyrogenic qualities and it was therefore considered likely that the stroma of disintegrated erythrocytes was responsible for these reactions, although this relationship was not specifically demonstrated.

Infected stored blood was rarely encountered. Two fatal reactions, manifested by the prompt occurrence of chills, fever and profound collapse, were discovered to be due to gross contamination of the injected blood with an organism of the coliform group, which interestingly enough, not only multiplied abundantly at refrigerator temperatures, but failed to hemolyze the stored blood, points of considerable practical importance.

The age of stored blood, barring the occurrence of hemolysis, did not appear to be a factor in the incidence of pyrogenic reactions. Moreover, the survival of transfused erythrocytes, estimated on the basis of Ashby counts performed on recipients with blood groups other than group O, proved satisfactory when stored blood was used within the prescribed time limits (fourteen to eighteen days), provided adequate refrigeration had been maintained throughout the entire period of storage. Unfortunately, once the material had been distributed from the blood bank depots, it too often was exposed to marked temperature fluctuations for several days so that the blood became prematurely aged prior to use. Field medical installations were not equipped with constant temperature refrigeration units; moreover, it was common practice on the part of these hospitals, on moving to a new location, to transport a supply of blood for immediate use on arrival, and during such movements, which occasionally entailed from twelve to forty-eight hours, refrigeration was usually discontinued altogether. The use of ice containers, eventually available, obviated this difficulty to some extent. While over-age blood served effectively in restoring blood volume and supplying a transient increase in oxygen capacity, and could be transfused, unless hemolyzed, without undue risk of untoward reactions, the duration of red cell survival after injection was relatively brief. The average rapidity of red cell destruction in the case of ten to fourteen-day old blood, administered soon after its receipt from the blood bank distributing center, was found to approximate 30 per cent during the course of the first three days, after which the rate of disappearance declined. This, of course, is in sharp contrast to the expected survival of fresh blood, a study of which indicated losses in the recipient of as little as 10 per cent after two weeks; it is significantly

more rapid than the rate of destruction of two-week old blood stored under strictly ideal conditions from the time of collection to the time of injection. Nevertheless, it represents a marked improvement over prematurely aged blood, the storage of which involved prolonged lapses in refrigeration or deleterious packing. The red cells from such blood in some instances were destroyed within three days, as much as 50 per cent occasionally disappearing from the recipient's blood in the course of twelve to twenty-four hours.

Hemolytic Transfusion Reactions. All stored blood distributed by the blood bank depots, representing most of the blood used in treating battle casualties, was of blood group O. The exclusion of bank blood of other groups was a wise precaution in view of combat conditions, for it obviated the necessity for time consuming compatibility tests in advance of each transfusion (a precaution which certainly could not have been dispensed with, for errors in blood grouping, recorded on identification tags, were encountered in as many as 10 per cent of soldiers.) Errors on the part of the blood bank, in the grouping of donor blood, were reported with extreme rarity, approximately five instances having been noted throughout the entire European campaign in which this blood was misrepresented as group O. How many fatal transfusion reactions were due to undetected major group incompatibility of fresh or stored donor blood is unknown.

Reactions due to Rh sensitization undoubtedly occurred, but there was little opportunity for its demonstration. Few hospital units possessed anti-Rh serum for the grouping of recipient or donor blood, and adequate sensitization tests had not as yet been described.[4] It is probable that in actuality clinical reactions due to the use of Rh positive blood in sensitized Rh negative recipients were rare occurrences in the preliminary overseas treatment of battle casualties, whose transfusion therapy was ordinarily completed within the time required for the development of anti-Rh agglutinins. It is to be expected, however, that a certain proportion of Rh negative soldiers, having received Rh positive blood, will have demonstrated subsequent evidence of sensitization, a problem which merits serious consideration by physicians responsible for their later care, should the latter include further transfusion therapy.

Another type of hemolytic transfusion reaction in which, not donor, but recipient red cells are destroyed, occurred following injection of group-O blood containing a high concentration of isoagglutinins which were incompatible with the erythrocytes of the patient.[5,6,7] This was manifested clinically by chills, fever, transient hemoglobinemia, occasional hemoglobinuria and moderate icterus. The reaction was not uncommonly observed in patients whose blood groups were A, B or AB, receiving group-O blood with a titer of anti-A or anti-B isoagglutinin in excess of 1:500.[8] Titers of this magnitude are found in less than 0.5 per cent of group-O donors; however, since the majority of seriously wounded casualties received blood from numerous donors, and since group-O blood was employed almost exclusively, this type of reaction was relatively common, comprising approximately one-half of all pyrogenic reactions observed in one series of over 500 consecutive blood transfusions. It did not appear to give rise to serious sequella, apart from those associated with the occurrence of chills and pyrexia, from whatever cause, in dangerously ill patients. Neutralization of the isoagglutinins in group-O donor blood by the use of type specific substance[9] was not attempted; however, late in the course of the war, blood distributed from the United States was screened with respect to isoagglutinin titer and high-titer blood designated for exclusive use in patients of blood group O.

A variant of this phenomenon, and one which appears to be fundamentally of greater importance than the overt type of hemolytic reaction, was the asymptomatic

blood destruction caused by the transfusion of blood or plasma containing incompatible isoagglutinins. This complication, detected in the course of studies employing serial Ashby counts and measurements of the blood volume,[8] appeared to have been a common occurrence in patients belonging to blood groups other than group O who received group-O blood or pooled plasma in very large quantities, especially when administered in the course of numerously repeated transfusions. Clinically, this complication was usually manifested solely by the development of mild icterus and an unexplained failure of anemia to improve with successive transfusions. Through laboratory investigation it could be shown that, whereas the donor red cells survived as expected after transfusion, the red cells of the patient diminished in number, and the surviving recipient cells often exhibited an increase in osmotic fragility, effects which were demonstrable to an increasing extent immediately following each successive infusion. Cases were observed in whom, following a succession of transfusions of this type, practically all of the recipient red cells were destroyed, only donor cells remaining. Of a series of patients, other than of blood group-O, who repeatedly received massive amounts of pooled plasma in the treatment of extensive burns, all exhibited these phenomena in varying degree, and in two cases demonstrating progressive fragility changes there developed an acute fulminating hemolytic anemia with hemoglobinemia, hemoglobinuria and almost complete destruction of the recipient red cells. No similar effects were noted in burned patients whose blood group was O, despite the administration of similar quantities of plasma. Thus, an additional argument is provided to substantiate the thesis[10] that whole blood (of homologous group), rather than plasma, is indicated in the treatment of burn shock. There is ample evidence, both from blood volume measurements and in view of the anemia which characteristically develops, irrespective of blood group and independently of plasma infusions, that a considerable red cell destruction is caused by thermal burns, although masked by a disproportionate loss of plasma. Despite the finding of an elevated hematocrit reading a marked oligemia may be present, for the correction of which the use of whole blood is not only justifiable but probably preferable. There is no physiologic disadvantage deriving from the presence of erythremia per se; from evidence available from physiologic studies[11] and from observations of cases with primary polycythemia, the arterial oxygen saturation should remain unchanged and the oxygen capacity of the blood become increased, which could be regarded as of possible benefit.

Repeated transfusions of pooled plasma employed for nutritional purposes are likewise regarded as potentially harmful, although to a lesser extent because of the relatively small quantities of plasma employed, excepting in cases in which the blood group of the recipient is "O." The same objection applies to the use of group-O blood in the routine treatment of anemia in patients of blood groups A, B, or AB. Although the repeated transfusion of "universal donor" blood very rarely gives rise to serious complications and does provide an added source of available iron, it must be regarded as an uneconomical procedure at best, failing, as it does, to accomplish satisfactorily the ends for which it is designed.

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The factors producing shock, whether primary or secondary, cause undue stimulation of the sympathetic nervous system. The function of the sympathetic nervous system is to maintain the blood pressure and increase the rate of the heart beat.

From "Surgery of Modern Warfare" edited by Hamilton Bailey (The Williams and Wilkins Company).

PENICILLIN AND ITS USE IN THE WAR WOUNDED*

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THERE is fairly general agreement among surgeons of experience in the forward area that no drug can be substituted for competent surgical management of wounds. There is also wide acceptance of the essentiality of whole blood for resuscitation in anticipation of blood loss during indicated surgical procedures. Such concepts inherently assign a tertiary and adjuvant status to chemotherapy. Alterations in the practical philosophy of wound management and in the quality and quantity of resuscitating infusions constantly introduced new variables in the program of wound management. For these reasons, it is unlikely that any completely satisfactory statistical analysis of the rôle of penicillin in military surgery can ever be prepared.

The British observations[1] upon the extraordinary efficacy of penicillin in certain established infections were widely confirmed in this country in 1943.[10] The drug was in short supply throughout the greater part of that year. This limited quantity of penicillin restricted military exploitation of the drug to investigative programs. The British Army adopted a plan of local treatment in recent wounds with the hope that serious infections might be prevented in large numbers by a small quantity of penicillin. The American policy reserved the drug for systemic administration in patients with established infection. Overseas distribution was designed initially to provide treatment for life-endangering infections, and the Zone of the Interior was assigned responsibility for the treatment of chronic suppuration. At the time these divergent policies of the British and American armies were announced, both seemed to be acceptable programs for using the limited supply of penicillin. The subsequent course of events revealed that these early policies exerted a profound effect upon developments in the philosophy of wound management. British surgeons focused their attention upon the bacteriologic sterilization of wounds, whereas American surgeons were compelled to rely upon surgical methods in the treatment of impending infection. Important differences of technic were a consequence of emphasis upon routine local therapy or upon a method reserving penicillin for systemic use in established infections.

The early British experience with local applications of penicillin has been reviewed.[4,9,20] Soft part wounds were dusted with penicillin powder after initial surgical treatment and were subsequently closed secondarily around rubber tubes for instillation of solutions of penicillin. Pleural instillation of the drug was practiced for hemothorax and empyema. Short courses of five to ten days of systemic administration of penicillin were given as a supplement to the local treatment of compound fractures. Tubes were sewed into major joint wounds for irrigation and infusion of penicillin. The net result was a comparatively reduced incidence of infection with pyogenic cocci and a probably reduced incidence of death due to infection. The clinical results won the approbation of many, but by no means all, of the surgeons privileged to review this experience.

The early American experience with penicillin in the treatment of suppurative compound fractures[11] established the inability of penicillin to sterilize dead or devitalized tissue. It was also shown that penicillin therapy did not permit the

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immediate surgical closure of wounds after removal of dead tissue in process of septic decomposition by proteolytic bacteria. The most important positive contribution of this study was the demonstration that systemically administered penicillin permitted operative intervention in suppurative wounds at a time of election without danger of exacerbation of invasive infection. Subsequent observations identified the technic of secondary, or delayed, wound closure after sequestrectomy as an acceptable and desirable component of this program of management of suppurating wounds. There emerged a philosophy of wound management defining a healed wound as its objective. Emphasis in the care of the local wound was given to its surgical preparation and secondary closure. Supportive blood transfusions and chemotherapy to prevent invasive infection were assigned essential but adjuvant positions.

As the American supply of penicillin increased in the early months of 1944, quantities became available for expansion of the original overseas program. The tactical situation in the Mediterranean Theater proved ideal for critical appraisal of the proposed plan of wound management. It is historically important that the major effort of this investigation was the clinical evaluation of a philosophy of wound management rather than an appraisal of penicillin therapy. In accordance with the original American policy of reserving penicillin for established infection, it was visualized that chemotherapy should be given for the demonstrated hazard of impending infection rather than as routine prophylaxis. Inasmuch as the experience of World War I had shown the beta hemolytic streptococcus to be the major hazard of infection in cleanly excised soft part wounds, it was believed that these could properly receive sulfonamides alone. Penicillin was reserved for the treatment of complicated soft part wounds and compound fractures. These general considerations have been discussed in greater detail elsewhere.[12] The fundamental surgical principles adopted were: (1) Early and complete initial surgery, (2) the wound left open and dressed with fine mesh gauze, pressure and splints, and (3) early closure of wounds showing no clinical evidence of infection.

Careful bacteriologic studies in the Italian Theater[13] demonstrated the susceptibility to penicillin of the invasive bacteria recoverable from war wounds. Other bacteria, lacking invasive attributes, were important as wound pathogens. Among these latter, the *Clostridium sporogenes*, *Pseudomonas pyocyanea*, *Bacillus proteus*, and para-*aerobacter* organisms were relatively or completely resistant to the action of penicillin. Suppuration associated with these bacteria was a common consequence of devitalized tissue and hematomas retained within a wound in spite of penicillin therapy. It was apparent from these studies that the usefulness of penicillin was limited necessarily to the control of invasive infection.

Toxemic *Clostridium* infection has been noted by many observers in patients receiving adequate dosage of penicillin. Hemolytic toxemia with bronzing and evidence of intravascular hemolysis does not appear to have been recognized as a complication of gas gangrene in war wounded. The toxemia observed is attributable to absorption of products of tissue putrefaction. Both devitalized muscle *and blood clot* appear clinically to possess the essential metabolites for release of this particular toxic factor. It was the opinion of MacLennan and Macfarlane[17] that penicillin contributed to the effective treatment of gas gangrene. Cutler and Sandusky[20] reported the occurrence of gas gangrene in five American airmen after initial operation with systemic penicillin therapy. In discussing this report, Garrod[5] notes, "In some at least of these cases the condition appears to have been inevitable gangrene in tissue deprived of its blood supply, and not active bacterial invasion of healthy muscle: that this was

the condition in Case 2 is clearly evident from a color photograph (Fig. 93)." In an analysis of 185 cases of gas gangrene treated with penicillin, Macfarlane[15] observed a statistically significant reduction in mortality for infections of the leg or arm. Infections in the thigh, buttock, and shoulder showed a persistent mortality of 40 per cent. The only variable in these two groups was the surgical accessibility of the infected muscle groups. Penicillin is effective in lowering mortality in gas gangrene after adequate excision of devitalized tissue, but is relatively ineffective without such supportive surgical excision. This final appraisal of penicillin therapy for gas gangrene received British[22] and American[19] concurrence.

In experimental studies,[6,18] the superiority of penicillin over other antibacterial agents was clearly shown. It was noted in these experiments that a barrier of fibrosis formed at the junction between devitalized and living tissue. The usefulness of penicillin to protect living tissues from invasive infection has been confirmed by clinical observation. Acceptance of this point of view is fundamental in establishing the systemic route as the administrative method of choice.

Devitalized tissue or hematomas permit the development of anaerobic infection. Penicillin, either locally or systemically, has not been demonstrated to prevent the ultimate septic decomposition of contaminated and devitalized tissue. It has been concluded that the local administration of penicillin is better than no chemotherapy at all,[2] but this study did not contrast local and systemic therapy. There is an increased incidence[11,16] and hazard[13] of infection with wound pathogens as a complication of local penicillin therapy. Local therapy is ineffective in a wound containing dead tissue and is not necessary in a clean wound. The greater effectiveness of systemic therapy has been recognized in American and British directives prescribing systemic treatment for complicated wounds and compound fractures.[19,21,22]

In conclusion, the British investigators demonstrated the antibacterial properties of local penicillin therapy in war wounds, whereas American investigators used systemic therapy to develop a new philosophy of wound management. This development was recorded by Churchill[3] and is currently in process of elaboration by surgical specialists relieved from active overseas assignments. In the main, these principles of wound management found British acceptance in Italy.[14] However, the evaluation of penicillin therapy for the war wounded demands a familiarity with both British and American experiences. Penicillin seems to have been partly responsible for improved results in surgical management. The improvement noted does not imply superior accomplishment in contrast with individual results achieved in World War I. It does recognize a high level of surgical achievement by all surgeons under a variety of tactical situations. Penicillin gave assurance that infection could be localized to the suppuration of devitalized tissue and blood clot and directed attention to the early closure of war wounds. This is most strikingly attested by comparison of the early pessimism[7] and the later enthusiasm[8] for the reparative surgery of compound fractures expressed by Hampton. On this basis, penicillin is today the most acceptable antibacterial agent available as an adjuvant to surgical management of the war wounded. The preference for systemic chemotherapy and the abandonment of local applications have been dictated by the philosophy of wound management evolved to afford the best care to the largest number of casualties.

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THE FUNCTION OF THORACIC SURGERY CENTERS IN WORLD WAR II

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THE policy of concentrating surgical cases in centers manned by personnel with special training for the problems involved was instituted by the Surgeon General in the early years of World War II. Among the centers designated for special care of surgical patients were five thoracic Surgery Centers in the Zone of the Interior.

During the last war, cases of suppurative pleuritis were segregated in a few hospitals but were usually under the auspices of the Septic Surgery Section. With this one possible exception surgical chest cases were included in general surgery and no specialization was employed. Moreover, twenty-five years ago there were few surgeons qualified or interested in limiting their activities to surgical diseases of the chest.

The concentration of patients with thoracic wounds and diseases of the chest has made possible technical advances in chest surgery and, more important, has afforded opportunities for comprehensive statistical studies involving both wounds and diseases of the chest. Five Thoracic Surgery Centers were established in general hospitals in the United States.* The purpose of this paper is to outline briefly the various problems encountered in a large Army Thoracic Surgery Center.

The advantages of the Center System are obvious. Opportunities for the concentration and conservation of specially trained personnel, including surgeons, nurses, physiotherapists and corpsmen provide superior facilities for diagnosis and treatment. Moreover, there are many problems in the treatment of thoracic sick and wounded which are unique. Not only surgical technics and anesthesia are somewhat different than those encountered in general surgery, but preoperative and postoperative care are highly specialized. Tremendous advances in physiotherapy and reconditioning of patients with thoracic wounds and injuries have been made during the past few years. Opportunities for the study of unusual numbers of tumors of the mediastinum, chest wall and lung have been possible. Suppurative diseases of the lung, including large numbers of cases of bronchiectasis, lung abscess and pulmonary cysts were seen and war wounds resulted in many cases of empyema, chronic draining sinuses, hemothorax and retained foreign bodies in the chest.

The Walter Reed General Hospital was one of the five Thoracic Surgery Centers established in the United States and a study of the admissions to this Center will serve as an index to the types of cases seen and the general principles of therapy employed in all Centers. The Chest Centers received thoracic sick and wounded from every part of the world where American troops are stationed. The deployment of cases to Chest Centers was from three main sources: First, battle casualties and patients who had contracted thoracic diseases while on overseas duty. These patients were ordinarily returned by the usual chain of evacuation and screened at the port of debarkation. A second important source of admissions was from Army dispensaries, station hospitals and regional hospitals throughout the United States. The third source which contributed to the majority of tumor cases was patients who were found to have intrathoracic neoplasms detected by roentgen examination, either at the time of induction into the military service or later when a roentgenogram of

* Baxter General Hospital, Spokane, Washington, Brooke General Hospital, San Antonio, Texas, Fitzsimons General Hospital, Denver, Colorado, Kennedy General Hospital, Memphis, Tennessee, and the Walter Reed General Hospital, Washington, D.C.

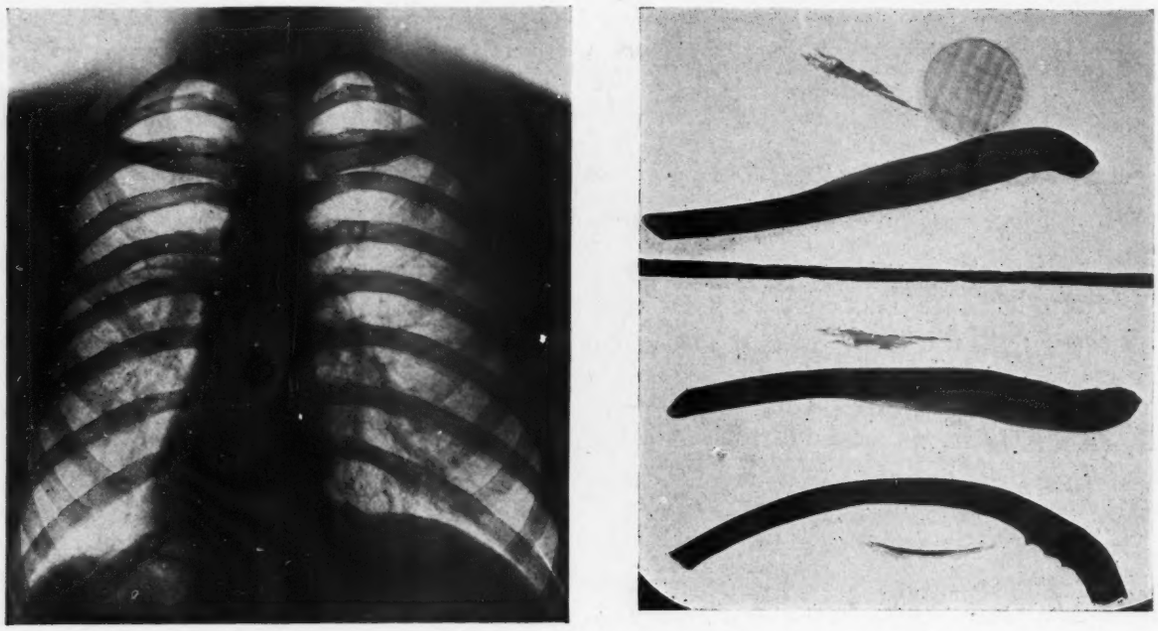

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FIG. 1. A, roentgenogram of chest of patient with two-inch spicule of rib in lung. The foreign body is not visible. The only significant finding is a defect of the left sixth rib which suggested an old injury. B, roentgenogram of resected rib and spicule which was penetrating the underlying lung.

the chest was made before the individual was separated from the service. The amazing number of potentially dangerous neoplasms which were detected by routine roentgenograms demonstrates clearly the advantage of this method of examination.

Important types of cases fall into three main groups and their subdivisions, namely, battle casualties, suppurative diseases of the chest and tumors of the chest.

Battle Casualties. Approximately 75 per cent of patients with battle wounds were well when they reached Thoracic Surgery Centers in the Zone of the Interior. The severity of their wounds and uncertainty of the ability of the patient to perform full military duty justified evacuation to the United States. The high percentage of cures in this group reflects the splendid care which they received at field and rear echelon medical facilities overseas. The patients who required further treatment included instances of retained foreign bodies, chronic hemothorax, chronic empyema, various chest wall defects, including chronic draining sinuses, bronchopleural fistulas, deforming scars, rib defects and hernias of the lungs.

Suppurative diseases of the lung, namely, bronchiectasis, lung abscesses, pulmonary cysts and chronic infectious granulomas, constituted a main problem. And many tumors of the lung, mediastinum and chest wall have been observed and treated.

It is not within the scope of this paper to discuss the relative frequency of various thoracic diseases or to describe in detail the treatment. Only points of general interest will be considered.

Intrathoracic Foreign Bodies. Retained intrathoracic foreign bodies have been frequent and interesting problems. Shell fragments, bullets, bits of clothing and wooden splinters have been removed from the lung, mediastinum and chest wall.

The initial and most important problem in the management of foreign bodies of the chest is whether or not the foreign body should be removed. It has been necessary to follow certain general but not absolute indications to determine this problem.

1. *Type of foreign body:* It is generally agreed that non-metallic foreign bodies, e.g., clothing, wood, etc., should be removed. Unfortunately, clothing and other foreign material which may be carried into

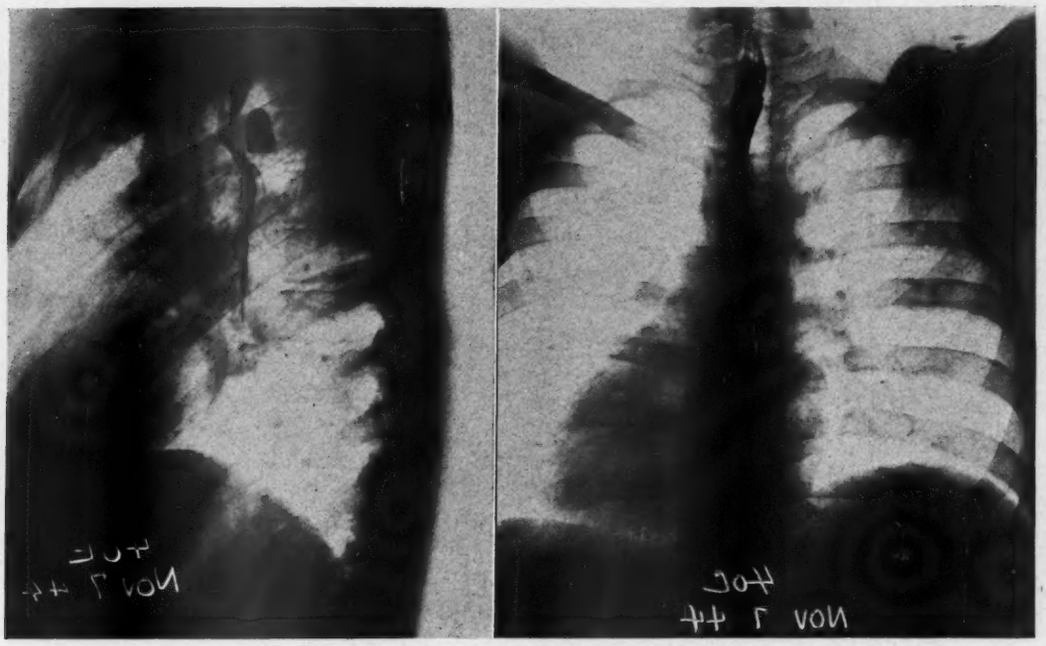

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FIG. 2. A, roentgenogram of chest showing esophagus visualized with barium and position of a 45 caliber bullet immediately posterior to the organ. B, anteroposterior view of the same patient.

the body with shell fragments or bullets may cast little or no shadow on an *x*-ray film. Even spicules of bone in the lung parenchyma are difficult to localize or identify. If, however, the presence of a nonradio-opaque foreign body is suspected exploration of the chest is in order. (Fig. 1A and B.)

2. *Symptoms:* When there are symptoms which may be attributed to a foreign body in the chest, surgical removal is indicated. If the lung is involved, the most common manifestations are pain and hemoptysis. Chest pain, however, associated with the presence of a foreign body is difficult to evaluate. Usually the pain is the result of injury to the chest wall. The sensory nerve supply to the pulmonary parenchyma is practically negligible; it is apparent, therefore, that pain originating from intrapulmonic foreign bodies results from injury to the pleura or elements of the chest wall.

3. *Size:* Attempts to establish the relationship between the size of retained foreign bodies in the lung and possible future prognosis have not been conclusive. Whether such a relation exists is problematical. Nevertheless, it has been necessary to establish an arbitrary limit on size of foreign bodies as an indication for surgical intervention. Radio-opaque foreign bodies, in which the greatest diameter exceeds 2 cm., have been considered large enough to warrant operative removal.

4. *Position of foreign bodies:* In certain cases foreign bodies which would not ordinarily be disturbed on the basis of size alone, were removed because of their position. This is true particularly when the fragment is intimately associated with important structures in the chest, namely, the great vessels, mediastinum and heart. It should be emphasized, however, that unless the foreign body was of a good size this indication for surgical removal was handled very conservatively. (Fig. 2A and B.)

5. *Psychosomatic factors:* Patients who have been informed of the presence of a retained foreign body often develop anxiety states. This is true particularly when the foreign body is in the chest. In some instances these patients are insistent to the point of obsession in requesting surgical removal. Occasionally, this factor alone justified operative interference.

Methods of Localization of Foreign Bodies. The precise localization of a retained shell fragment or spicule of bone in the thorax may test the ingenuity and patience of the surgeon and radiologist.

Roentgenograms. The routine use of the frontal and lateral projections of the chest will furnish a three dimensional concept of the thorax which localizes with reasonable accuracy an opaque foreign body. Examinations with the fluoroscope and oblique projections of the chest are useful and are of particular value when the foreign body is in intimate contact with mediastinal structures. Fluoroscopic examination will usually aid in establishing whether or not the fragment is in the chest wall or in the lung parenchyma and if the foreign body is in or near the pericardium or myocardium the motion of the fragment with the cardiac impulse will be established.

Angiocardiograms. Angiocardiogram technic employed at Walter Reed General Hospital was instituted by Lieutenant Colonel George P. Robb, Chief of the Cardiovascular Section. A brief description of this procedure is given to illustrate the value of the angiocardiogram in the accurate localization of foreign bodies that are in intimate contact with the vessels of the mediastinum. This procedure is divided in two stages, the first stage being the determination of the circulation time from the arm to the tongue and the arm to the lung. Arm to tongue circulation is determined by the injection of cecholin sodium solution and the accurate stop watch measurement of the elapsed time between injection and onset of bitter taste. The arm to lung circulation time is also obtained if the circulation time exceeds a certain value. This latter procedure consists of measuring the elapsed time between injection of an ether solution and when it is first detected on the patient's breath. When these time factors are determined, a second stage is then carried out by positioning a patient before a stereoscopic cassette. The angiocardiograms are then obtained by the introduction of diodrast concentrated solution into the veins. This radio-opaque medium does not disseminate immediately in the vascular system. Instead the rapidly injected diodrast forms a "bolus" which may be followed from its point of injection through the cardiovascular system until it is broken up in the peripheral vessels. By careful evaluation of the circulation time, which has been previously determined, the approximate time of opacification of the intrathoracic cardiovascular system can be obtained. In this way separate roentgenograms can be made showing contrast filling of the right ventricle and pulmonary arterial tree, then the left ventricle and aorta. In the same way the superior vena cava and the right auricle are opacified at different times than the pulmonary veins and the left auricle. The information obtained from this procedure is precise and it is often possible to get an almost exact location of the mediastinal foreign body in relation to the mediastinal-cardiovascular system.

Opaque Markers on Chest Wall. Some surgeons employ various markers on the chest wall. Small bits of metal may be taped to the chest wall after the foreign body has been localized by fluoroscopic examination. The position of the marker may then be checked by the use of roentgenograms taken in appropriate positions. Another technic which has been used, both for localization of foreign bodies and preoperative localization of lung abscess, is to inject a few cc. of dye, either methylene blue or gentian violet mixed with lipiodol, into the chest wall at the site where the intrathoracic lesion is in contact or nearest to the chest wall. This furnishes both a visible and radio-opaque landmark for the surgeon.

The Berman Locator. The Berman Locator first received considerable publicity when it was used by Dr. John Moorhead at Pearl Harbor. This instrument has proven to be a valuable adjunct in the localization of magnetic foreign bodies, particularly when the foreign body is deeply located in the lung parenchyma and mediastinum.

The Berman Locator has a long handled probe which may be sheathed in a sterile rubber casing and cloth sleeve. With this protective covering, it may be used to explore any cavity that is entered surgically. As contact with a metallic foreign body is made by the tip of the probe, a constant sound vibration is heard. This sound varies in volume directly in proportion to the distance between the probe and the foreign body. When the Berman Locator is properly used, the operative removal of magnetic foreign bodies is greatly facilitated. It should be considered, however, strictly as an adjunct to surgery. In the hands of an untrained operator it will offer nothing more than a false sense of security that is readily demonstrated when the thorax is explored.

The Foreign Body Register. The fate of retained foreign bodies is not entirely understood. Although numerous papers have been written on military surgery relative to this subject, the evidence is still inconclusive. No one knows whether or not all foreign bodies of the lung should be removed. There is no assurance that a currently asymptomatic foreign body will not cause trouble later. Operation was not advised in many of the cases of retained foreign bodies seen at Walter Reed General Hospital. In many of these cases the missile appeared to be clinically quiescent and for one or several reasons was not disturbed. All of these patients have been recorded in the Foreign Body Register. Periodic surveys will be made at intervals in an effort to determine the eventual outcome of this group. If the Register succeeds in its purpose, a large amount of pertinent information will be available in future years.

CHRONIC HEMOTHORAX

Perhaps the most interesting cases returned from overseas theaters have been those with chronic hemothorax. Since hemothorax is an almost expected complication of wounds penetrating the pleural space, the incidence of this entity was high. The management of the acute phase by early and complete aspiration of the chest was instituted in front line hospitals. It may be stated here that aspiration without air replacement was the general policy in therapy. Only a small percentage of the acute cases progressed to the chronic phase. These comparative few required radical surgical intervention to effect a cure.

Treatment of Chronic Hemothorax. Usually more than eight weeks had elapsed from the time of injury until the patient returned to the United States. Thoracentesis was no longer of value because of the extensive organization of blood clots. With few exceptions these patients were treated by exploratory thoracotomy. An overlying rib was resected and the cavity opened widely by means of a rib spreader. After all organized clots and liquid were evacuated, a careful inspection of the cavity was made. An excellent article on this subject by Burford et al. has described the technic of decortication in chronic hemothorax and postoperative empyema. Burford also notes that the optimum time for decortication seems to be between six and eight weeks after the development of the hemothorax. This optimum time refers to that period when a good "peel" is most easily developed. It is of interest to record that many cases at Walter Reed General Hospital were treated by decortication as late as six months after being wounded and did very well. The opinions of surgeons at this hospital in general support that of Burford and his associates, but we do believe that decortication is still of value many months after the optimum period has elapsed. (Fig. 3A and B.)

CHRONIC EMPYEMA

Chronic empyema resulting from war wounds has been the most common and the most serious chest complication treated in the Thoracic Centers in the Zone of Interior. In spite of the universal use of chemotherapy in the management of war wounds, an important incidence of chronic suppurative pleuritis has persisted. In the

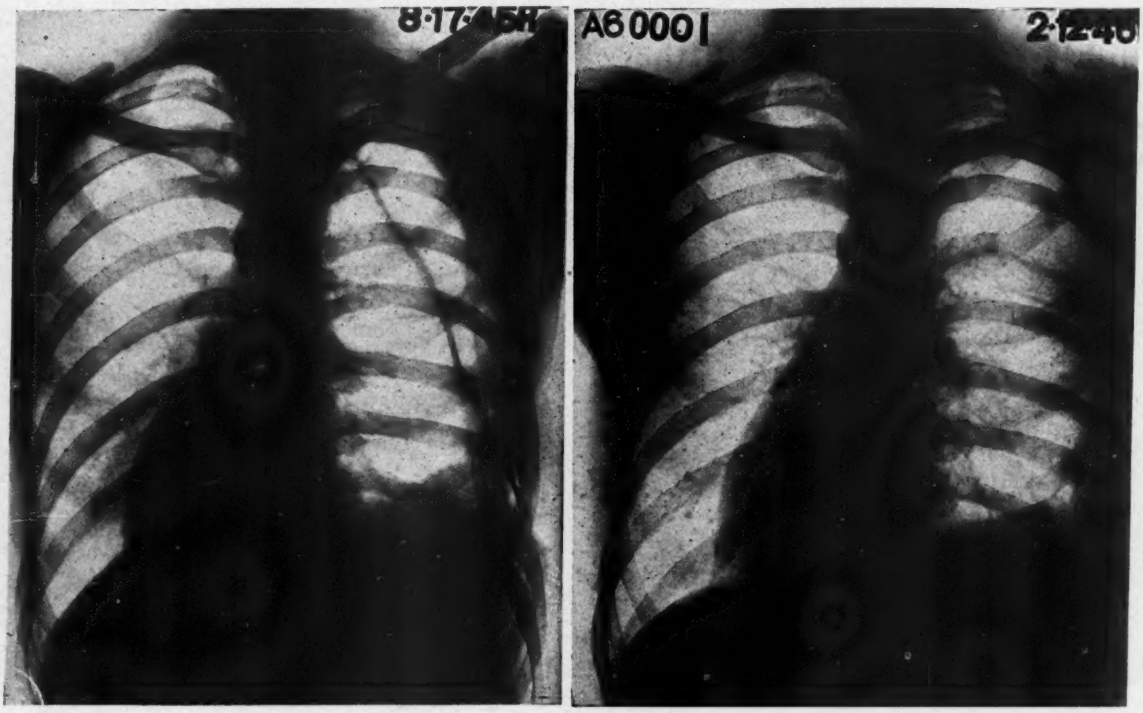

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FIG. 3. A, roentgenogram of the chest showing chronic empyema which resulted from an infected hemothorax. The chest has been adequately drained by open thoracostomy. B, roentgenogram of chest six weeks after decortication operation for chronic empyema. This case illustrates the possibilities for restoration of lung function, obliteration of chronic empyema and conservation of the chest wall in patients who have had preceding injury.

majority of cases, the disease has been secondary to an infected hemothorax. Patients with empyema have usually been treated in rear echelon hospitals before evacuation to the United States. On arrival at the port of debarkation the patients with empyema have been given high priority. These patients were usually sent to a Thoracic Center even though other unrelated diseases may have been present that required specialized care.

Treatment of Chronic Empyema. The most common method of treatment of chronic empyema in overseas theaters involved dependent open drainage. This procedure was primarily designed to prepare the patient for evacuation to the Zone of the Interior. In the early phase of the war an occasional patient returned with closed intercostal catheter drainage. These patients were definitely in the minority and presented real evacuation problems because they were burdened by portable water bottles that dangled between their knees. In the last year of the war closed seal drainage was seldom seen. The overwhelming majority of surgeons used open tube drains in the dependent part of the empyema cavity.

Upon admission to Walter Reed General Hospital, the general conditions of patients with empyema thoracis were carefully evaluated. Since most of these patients reflect the effects of chronic sepsis and general debilitation, immediate treatment involved general physical rehabilitation. The first step in this procedure was careful physical inspection of the patient and admission *x*-rays to determine the adequacy of drainage. Frequently, the initial surgery had been conservative and it was necessary to revise the thoracostomy wound to provide adequate drainage. In many cases this simple revision operation, coupled with intensive specialized physiotherapy, would be enough to accomplish complete obliteration of the cavity. Even if a cure was not obtained, the patient's

general physical condition was invariably benefited to a marked degree. After these simple procedures had been performed and the patient allowed time for general improvement, he was considered for further surgical procedures of a more radical nature. Generally, a simple rule was followed as an indication for surgical correction of a chronic empyema cavity. If a well drained empyema cavity shows no reduction in size after a period of six weeks, the patient was considered a candidate for surgical intervention. In this connection it is important to emphasize that the only reliable method for determining an empyema cavity is by accurate measurement with fluid. The only valid reason to omit the measurement of an empyema cavity with fluid is the presence of a bronchial fistula. The introduction of any fluid in this type of case is potentially dangerous.

Several procedures were employed in the treatment of chronic empyemas. In all cases a decortication operation was attempted when large cavities were present. Frequently, this procedure has been very successful and has afforded the patient a complete cure. This procedure is very similar to that described by Burford and his associates in almost every detail. In some cases, however, the thickened membrane on the visceral surface of the empyema cavity was not amenable to decortication and a procedure of second choice was employed. The term "internal pneumonolysis" was used at Walter Reed General Hospital to describe this operation. Actually this is not a very descriptive term and a brief explanation of the technic may be of interest. The operation is only employed when decortication is abandoned because a "peel" is not obtained. Briefly, this procedure is initiated in the same manner as a decortication operation by resection of a rib and wide exposure of the entire empyema cavity. When the "peel" cannot be removed from the underlying pleura without damage to pulmonary tissue, the pneumonolysis is carried out by carefully incising the membrane around the periphery of the empyema cavity. This incision is carried through the membrane where the parietal and visceral portions conjoin. The visceral portion is left adherent to the underlying lung and the surgeon then carefully frees the lung from the noninvolved portion of the thorax. This latter procedure is usually easily done by blunt dissection, using the gloved fingertip or dissecting sponge. After dissecting free the underlying lung, positive pressure is then carefully applied and the lung is re-expanded. As the partially collapsed lung is re-expanded, it usually fills the entire chest cavity and the empyema space is obliterated. Closure is similar to that of a decortication operation. This procedure is of real value in that it often obviated thoracoplasty and is not in itself a deforming operation. (Fig. 3A and B.)

The importance of adequate physiotherapy in the treatment of chronic empyema cannot be overemphasized. A competent physiotherapist trained in problems of chest diseases can do an inestimable good in helping the patient acquire maximum re-expansion of the lung and in overcoming chest wall deformities that are commonly seen in chronic empyema.

CHEST WALL DEFECTS

The remarkably low incidence of serious chest wall defects in the many war casualties of the thorax can be at least partially explained by the splendid emergency treatment wounded men received. The control of secondary infection by adequate surgery and chemotherapy practically eliminated the ghastly sloughing wounds of the chest wall common twenty-five years ago. When serious defects of the chest wall were encountered it was almost always possible to effect a satisfactory repair with the skin, muscle and bone of the thorax. In a few isolated instances tantalum plates were employed to bridge the defects in the chest wall. These endeavors were commonly disastrous. The tantalum plate acted as a foreign body and either sloughed out or had

to be removed. True hernias of the lung are relatively rare.

BRONCHIECTASIS

Of the chronic suppurative diseases of the chest diagnosed at Walter Reed General Hospital, the large majority were bronchiectasis. This entity proved to have an unexpectedly high incidence in the armed forces. In the years of 1942 and 1943 no less than 3,777 cases of bronchiectasis were admitted to Army hospitals. Even if one assumes that many patients did not have true bronchiectasis, it becomes apparent that the disease constituted a real problem. All of these men had passed induction examinations, including roentgenograms of the chest. This knowledge makes us wonder how many undiagnosed cases there must be in the general civilian population today. The diagnosis of bronchiectasis ultimately depends on a bronchogram. We can assume that many more patients were incorrectly diagnosed because facilities for lipiodol instillation into the tracheobronchial tree are not available at all Army installations.

All types and degrees of bronchial dilatations have been seen. The majority of patients had unilateral disease and could be treated successfully. In some instances patients with bilateral disease were benefited by surgical therapy. The only really satisfactory treatment for bronchiectasis is surgical extirpation of the diseased tissue.

Treatment of Bronchiectasis. In the Army the policy was to discharge those patients who would not submit to operation or who were not amenable to surgical treatment. The diagnosis was suggested by clinical manifestations but was always confirmed by bronchography. Those patients who refuse operation or who have extensive bilateral disease are given medical discharge from the service. Advanced cases who are not candidates for surgery are usually transferred to a Veterans Administration facility for continued hospitalization.

Patients who were operated upon for bronchiectasis showed gratifying improvement. In most cases operation was confined to single lobectomy. Next in frequency were the cases with combined left lower lobe lobectomy and lingulectomy. Less commonly, segmental resections were done when the disease was confined to one segment of a lobe. When a patient had bilateral involvement of his lungs and was still considered a candidate for surgery, two separate operations were performed. Usually the more involved side was operated upon first and the other after an interval of four to six months.

Preoperative Preparation for Lobectomy. Before the sulfonamide derivatives and penicillin were available, the preoperative preparation for lobectomy consisted of careful postural drainage and measures to improve the patient's general condition. The introduction of penicillin has offered great advantages and since this mold has been available it has been customary to perform pulmonary resections with so-called penicillin protection. For the patients at Walter Reed General Hospital, Romansky's technic of administering a single injection of 300,000 units of penicillin in beeswax and peanut oil has been utilized. The penicillin is given from three to seven days before operation and continued until the temperature remains normal after the operative procedure. Another important preoperative measure is the preparation of the patient by the physiotherapist who carefully instructs the surgical candidate on breathing exercises which will be carried out through the postoperative program.

The details of operative technic will not be discussed in this paper; however, a few essential principles will be mentioned. The lobectomies in this series were almost always performed by the ligation of each vessel in the bronchi and the hilum of the lobe rather than with a torniquet. In all cases of partial pulmonary resection, the pleura is drained by means of an air-tight catheter connected to water seal suction. In most cases the drainage tube or tubes

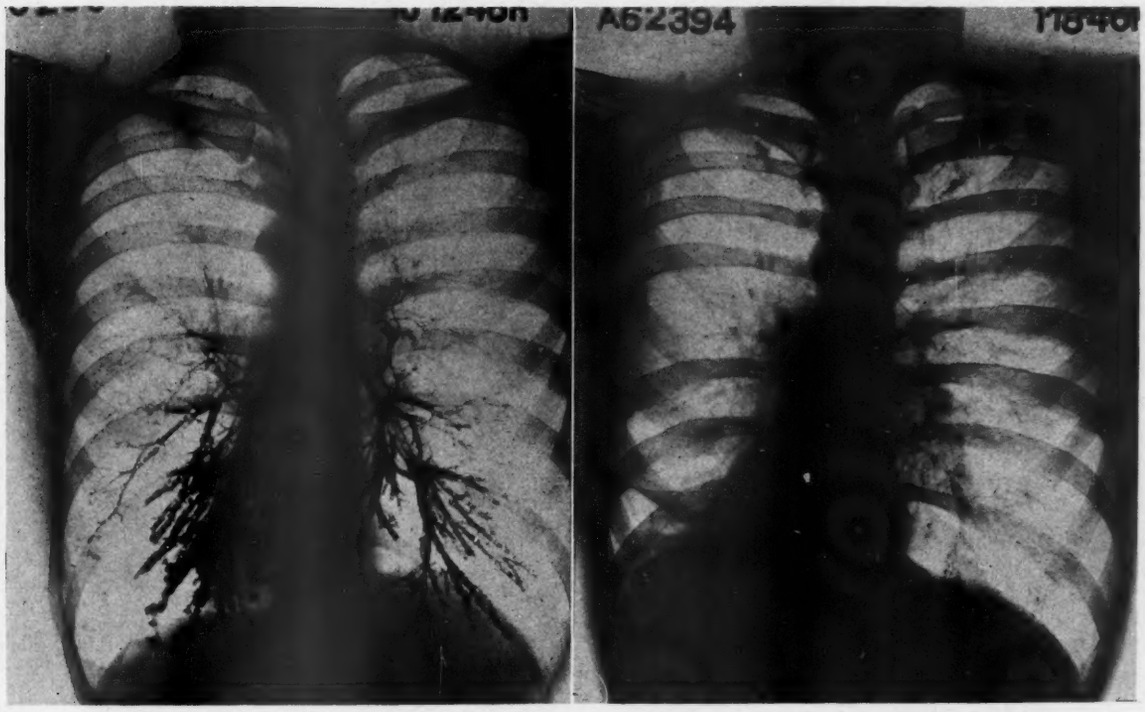

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FIG. 4. A, bronchogram demonstrating bronchiectasis of the left lower lobe and lingula of the left upper lobe with minimal involvement of the right lower lobe. B, roentgenogram of the chest twenty-one days following left lower lobe lobectomy and lingulectomy.

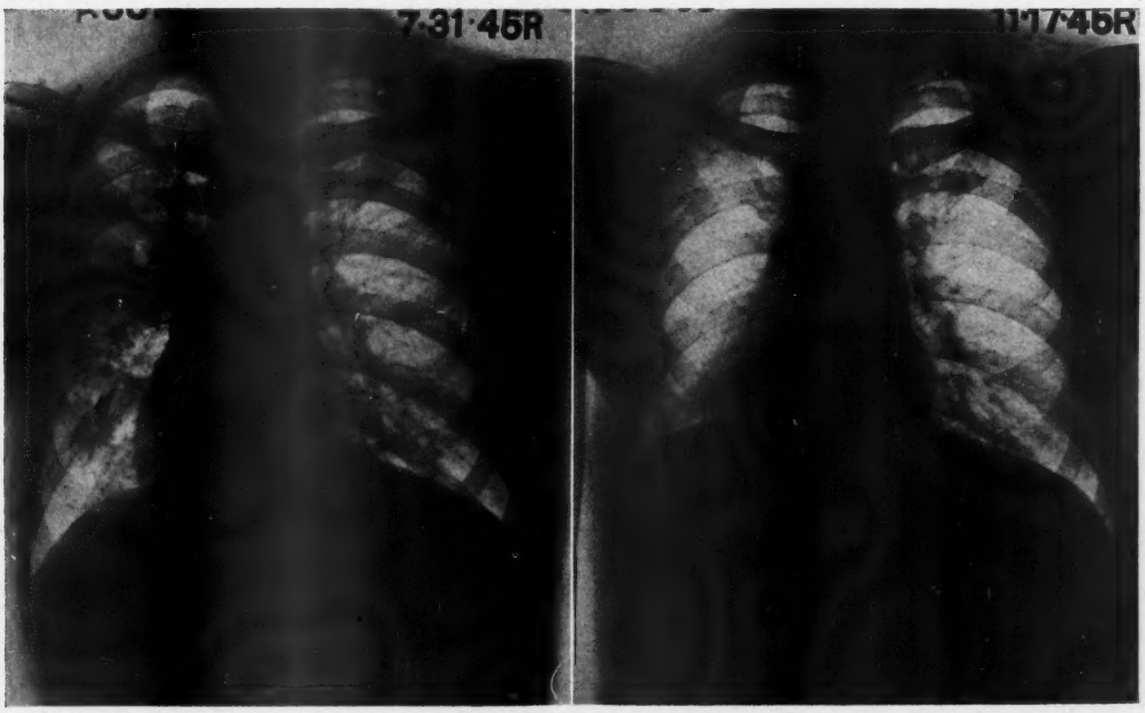

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FIG. 5. A, roentgenogram of the chest showing chronic lung abscess in the left upper lobe. B, appearance of the chest six weeks after left upper lobe lobectomy.

are removed in twenty-four to seventy-two hours.

Bronchoscopy is performed routinely in the operating room before the patient regains consciousness. This guarantees the removal of mucus or blood which may have accumulated in the tracheobronchial tree. Following the bronchoscopy, a portable roentgenogram is made in the operating room. If the postoperative roentgenogram reveals atelectasis or unsatisfactory re-expansion of the remaining lung tissue, immediate corrective measures are instituted.

Postoperative Care. Three hundred thousand units of penicillin were given daily during the postoperative period until the patient was symptom free. Daily roentgenograms were taken at the bedside to keep constant check on the expansion of the remaining lobe or segments of lung. Early activity of the patient is encouraged. An effort was made to have the patient dangle his feet in twenty-four hours and get out of bed in two or three days. Many visitors are surprised to learn that the postoperative course of a patient with an uncomplicated lobectomy is as uneventful as of one with a simple appendectomy. When the remaining lung tissue had expanded to fill the hemithorax and the patient's general condition warranted it, he was given a recuperation furlough. Many of these patients returned to full duty following a lobectomy. (Fig. 5A, B and C.)

LUNG ABSCESS

It will be difficult in the final analysis of World War II thoracic sick and wounded to determine the incidence of lung abscess. It is highly probable that the extensive use of penicillin and the sulfonamides has lowered the rate of pulmonary abscesses tremendously. It is likely that many abscesses were detected in the acute phase and cured by adequate chemotherapy and the usual medical régime. Because of this, many patients were treated in smaller medical facilities and never reached the thoracic centers. Only those patients who developed the chronic lung abscess were transferred to a center. These patients had already received more than adequate amounts of penicillin and sulfonamides and were transferred primarily for surgical consideration.

Treatment of Chronic Lung Abscesses. For many years excisional surgery in the treatment of chronic lung abscesses involved such high mortalities that drainage was usually employed. The incidence of cures obtained by simple drainage of chronic lung abscesses has been low. Too often an entire lobe is destroyed and not infrequently the infection has traversed interlobar fissures invading adjacent lobes. In these cases drainage may possibly improve the condition by decreasing the amount of sputum and perhaps make the patient fever free, but he continues to be a chronic invalid. It is our belief, therefore, that if the lesion is chronic with evidence of multiple consolidation, atelectasis or involvement of an entire lobe, excisional surgery should be recommended. Other reasons for choosing pulmonary resection instead of drainage are persistent serious hemorrhage, either from a drained or undrained abscess cavity, involvement of an entire lobe, particularly an upper lobe, or, if more than one lobe is involved, and the possibility that a neoplasm is the underlying factor.

It is admitted that the operative risk of lobectomy for chronic lung abscess is far greater than lobectomy for bronchiectasis. In our own series of sixteen cases, the operative mortality was 6.4 per cent. It must be emphasized, however, that all of these patients were young and good risks for major operations. Even if one accepts a high operative mortality, a large number of cases may be salvaged by excisional surgery who are otherwise doomed to a life of chronic invalidism.

It is highly important that the lobectomy be performed by the individual ligation technic in an effort to prevent complicating empyema. It is in this group of cases that particularly dangerous putrid postopera-

tive empyemas may develop. (Fig. 6A, B and C.)

Fig. 6. Angiocardiogram showing visualization of the aortic arch and position of metallic foreign body which is embedded in the anterior myocardium.

CYSTIC DISEASE

A patient with congenital pulmonary cysts does not necessarily have a suppurative process of the lungs. However, such a high percentage of the lung cysts found in Army personnel had become infected that this entity was considered one of the chronic suppurative diseases of the chest. Since cystic disease had been diagnosed by routine roentgenograms in so many of these patients and had no associated symptoms, it is our belief that cystic disease of the lungs will be more frequently recognized in future years. Almost every soldier in World War II was exposed to two or more radiologic examinations of the chest in an average period of less than three years. For this reason there was a comparatively high incidence of diseases that were heretofore considered rare. The recognition rate of cystic disease of the lung will rise with increased roentgen opportunities for the average civilian patient.

The term, cystic disease, as used at Walter Reed General Hospital includes the bronchiogenic cysts. It was believed that all cysts of the lungs and tracheobronchial tree are probably bronchiogenic in origin and have potential or direct communication with the bronchi. Lung cysts which are usually surrounded by parenchyma were frequently thin-walled spaces and easily overlooked on the examination of the roentgenograms. When these cysts became infected, they usually filled with fluid and produced symptoms similar to a lung abscess. Occasionally, these infected cysts were so large that the patient was admitted with the diagnosis of encapsulated empyema.

The bronchiogenic cysts invariably appeared as areas of increased density on the roentgenogram. These cysts were most commonly found in the posterior mediastinal regions associated with hilar structures. Occasionally, however, they were removed from the parenchyma of the lung and not associated with the major divisions of the bronchi. Because of their increased densities, they were frequently mistaken for other benign tumors and, on more than one occasion, for solitary metastasis. At operation, many of these cysts were very thin-walled and filled with fluid. Others had a dense collagenous material occupying the cyst cavity that resembled mucin. The thin-walled cysts that contained fluid were occasionally observed to vary in density when repeated radiologic studies were made. This observation is explained by fluctuation in the contents of the cyst. If a small communication with a bronchus is present, the cyst may expel part of its contents on occasion. This has been demonstrated following bronchoscopy when the patient has had violent coughing.

Treatment of Lung Cysts. Simple lung cysts may be discovered in all age groups. It is obvious that the discovery of a noninfected cyst is not in itself an absolute indication for surgery. All patients with solitary or multiple asymptomatic cysts were considered candidates for elective

surgery only. Since most of these thin-walled cysts cannot be shelled out like a benign tumor, removal by either lobectomy or segmental resection is usually necessary.

Infected cysts were always treated by surgery. Before the sulfonamides and penicillin were available, large infected cysts were often treated primarily by drainage. When adequate drainage was obtained, excision of the cyst was necessary to effect healing. For the past two years at Walter Reed General Hospital infected cysts have been excised without preliminary drainage. Penicillin protection has probably been an important factor in the success with these cases.

TUMORS

It is not in the province of this report to describe in detail the many and various types of thoracic tumors found in Army personnel. Routine roentgen examination resulted in the discovery of many neoplasms. For example, 109 mediastinal tumors were discovered in five chest centers and successfully treated. There were many cases of bronchiogenic carcinoma despite the young age group encountered. Results in this series were discouraging because in most instances the lesion was inoperable by the time the diagnosis was made and because there was a high incidence of highly malignant peripheral bronchiogenic carcinoma which gave no warning until metastasis precluded successful treatment. The results in patients of the older age groups in whom centerally located squamous cell carcinomas were found were far better than in young individuals.

CONCLUSION

Thoracic Surgical Centers were established for the first time in World War II. The advantages of the center system have proven themselves by increased professional efficiency in the care of sick and wounded patients. Secondary to therapeutic efficiency have been the opportunities of studying large, compact series of patients with chest diseases.

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SURGICAL MANAGEMENT OF WAR WOUNDS OF THE ABDOMEN

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THE management of abdominal wounds incurred in war has been the subject for constant review during each new war and for a relatively short period thereafter. The mortalities reported have gradually improved as methods of evacuation have been speeded up, and early mass surgery with adequate supportive treatment and blood replacement combined with newer methods of chemotherapy been made available in forward areas.

PRE-HOSPITAL MANAGEMENT

There is not room nor intention here to discuss the evacuation of the wounded but the various progressive treatment stations in order will be recalled: The first aid, the clearing station, and the Surgical Hospital or the Field Hospital augmented by Surgical Teams, and the Evacuation Hospitals (400 bed semi-mobile and 750 bed types) all in the forward or combat zone. It has been the policy of the United States Army in general to avoid major surgical operations in institutions forward of the Surgical or Field Hospitals surgically augmented. Isolated airborn or armored units at times have had to disregard this policy but the early and conclusively demonstrated fact that abdominally wounded will not stand transportation postoperatively before ten days or even two weeks has made it mandatory that they be transported preoperatively to such a point where adequate surgical preparation, treatment and postoperative care without interruption for transportation before their condition permits, may be achieved. The early deaths in the abdominally wounded are largely the result of shock, either alone or more frequently associated with hemorrhage. Shock, the result of the initial trauma, will, if hemorrhage is not too grave a factor, usually respond enough to plasma infusion, conservation of body heat and alleviation of pain, to allow the patient, properly splinted if associated injuries indicate, to be transported to the adequately equipped mobile operating theatre. We thus see that those caring for the abdominally wounded, forward of the hospital institutions, can only dress their wounds, treat the patient's shock, give them morphine as needed, control external visible hemorrhage (by direct hemostasis) while trying to speed their evacuation. It has been clearly demonstrated that if hemorrhage has been of any degree, whole blood is needed and makes the best replacement, and during the latter phases of the war, this was available at the clearing stations, while plasma was available at the first aid stations. It is the author's personal belief that too often technical complications beyond the control of the administrator, as available transfusion needles being too small or filters too tightly packed or clogged, interfered with rapid administration of the plasma, the procedure thus requiring too long a time, thereby not giving the patient as prompt a boost as needed while allowing the passage of valuable time before he was evacuated to the hospital. Certainly, these difficulties constantly beset us in the forward hospitals. In the American Army, the immunization of all its members against tetanus early proved itself, and so during the time the patient was receiving his early supportive therapy, tetanus toxoid in a stimulating dose was always given. As the war progressed penicillin

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became available and early and prompt administration of the drug has seemed worth while, although when contamination of the abdominal cavity by penicillin resistant organisms has generally occurred (Bacillus coli) its therapeutic benefits have been limited. The early use of intravenous sulfonamide preparations would seem advisable and perhaps when the next war supervenes, all those in immediate danger will keep their intestinal bacterial flora to a minimum by pre-battle sulphthaladine or sulfasuxidine, or oral streptomycin.

Not infrequently a perforating missile will upon leaving the abdomen tear away a considerable portion of the abdominal wall and either carry with it or be followed by considerable lengths of small intestine. The author has seen repeated instances when under these circumstances the eviscerated bowel has been free of perforations. The question of early intra-abdominal replacement prior to reception at a hospital immediately presents itself. If the eviscerated intestine, though intact, shows signs of interference with its blood supply, this may be due to torsion or tension on the mesentery; and under these circumstances, especially if dust and dirt has not been ground into the intestinal wall due to clothing protection, careful replacement would seem indicated. Exposed loops which remain out may become gangrenous if forced delay in operation keeps them exteriorized for prolonged periods. Quite obviously, however, if the circulation of the bowel has been compromised as the result of direct trauma to its blood supply, nothing more than a protective external dressing is indicated. In general, if the loops are covered with soilage, gentle cleansing with preferably warm saline, the abdominal wound being protected, should be done, the loops then sprinkled with sulfanilamide crystals, and covered first with dressings moistened in saline (aid stations, or clearing stations at least) and finally heavy bulky dressings, the whole gently but firmly strapped in place with adhesive. If the patient has had adequate shock treatment and is not bleeding, he can be transported quite well in this condition. Likewise, in general, if there is considerable loss of the abdominal parietes, adequate protective dressing should also be applied.

PREOPERATIVE MANAGEMENT

In the preoperative preparation of these patients, upon reception at the point where definite surgery is to be performed, thorough estimation of this patient's condition is essential. The great majority of the abdominally wounded will require at least one blood transfusion prior to surgery and those bleeding or who have lost considerable blood may need as much as 2,000 cc. or even at times almost double this amount. An early accurate estimation of the degree of shock, the amount of blood loss, and the presence of continued bleeding are of prime and foremost importance in the management of these patients. In war, associated injuries are the rule and bleeding from an extremity wound may be contributing appreciably to the patient's shock. Emergency control of the latter thus forms a definite part of the shock therapy. The more severely shocked patients were usually given oxygen through a B.L.B. mask as it seemed definitely to contribute to a favorable response. Patients in shock who are not bleeding will usually maintain their rise in blood pressure achieved as the result of their supportive treatment. In general, it has been the author's experience that blood and plasma in a ratio of about 1 to 1 or slightly greater, gave the best overall response. Plasma was begun immediately on all shocked patients upon admission because of its ready availability and blood, when cross-matched, then started in the other arm, if, as so often unfortunately was not the case, the other arm was not denied because of injury. Blood was routinely cross-matched although at times the severity of the emergency will make this omission man-

datory. Those patients in whom an initial favorable response to anti-shock therapy is not maintained are probably still bleeding and every effort should be made to get these patients to the operating room with all speed, whole blood replacement being kept going during transfer to the operating room and during anesthetisation and subsequent operative work. Patients who respond readily to this blood or plasma therapy, whose abdomens are tense, are probably suffering from a perforated viscus and early peritonitis. However, in these, if the missile has only penetrated and not perforated the abdomen, there is usually sufficient time to allow an *x*-ray of the abdomen to try to determine the location of the retained foreign body. This information is always helpful in deciding the best incisional approach. It has been the common experience of those managing the abdominally wounded that the additional time necessary properly to stabilize the patient's circulation is more important in reducing mortality than avoidance of a few extra hours of soilage by intestinal contents. This period often is three to four hours in length while actually under the mass flooding of the hospital by casualties during particularly heavy action, the unavoidable surgical backlog may force a longer preoperative period even up to eight hours at times, under unusual circumstances rarely more. In the author's personal experience in the management of 457 abdominally wounded, brought to the hospital for initial surgical treatment, thirty-eight died before operation could be performed. Some of these, obviously moribund, never responded to therapy; others made a temporary slight response but slipped back into irreversible shock before operation could be arranged or even while being transported to the operating room. A pressure over 100 mm. of mercury systolic was one of the aims of preparation along with a pulse below 120 if possible. The variations in the efficacy of treatment and promptness of surgical operation will always vary with the varying duress of circumstances and the surgical backlog. The mortality some months was 10 per cent and almost all came to surgery; other months it reached 30 per cent, with appreciable mortality in the shock wards. The overall mortality in the 457 abdominally wounded primarily handled on the author's service was 21.2 per cent. The postoperative mortality on 379 operated upon was 15.3 per cent. These figures do not include fifty-five thoraco-abdominal cases reported elsewhere, nor forty-nine postoperative patients received at various times from field hospitals or clearing stations (armored) in front of us.

In war, many have eaten fairly recently prior to their wounding and an attempt to evacuate the stomach of its liquid contents should be promptly made. Larger undigested food particles will not be evacuated; but if air and liquid gastric contents are evacuated, anesthetic accidents will be avoided, and the patient's response to anti-shock therapy will be more prompt. This has been repeatedly seen when acute gastric dilatation was found in patients with severe extremity wounds without any abdominal penetration, the patient responding poorly until after the dilatation was relieved.

Before leaving discussion of the treatment of shock in these patients, a note of discretion is interjected with regard to indiscrimate fluid administration. For a while 20 per cent of our postmortem specimens showed hemoglobinuric nephrosis on microscopic section. As the war progressed across the European Continent, those wounded by fragments from enemy artillery more often showed associated blast injury effects and in a number of cases fatal pulmonary edema resulted, perhaps precipitated by too energetic fluid replacement though it might have occurred even on a régimé of restricted fluids. If evident, as shown by pulmonary râles, hemoptysis or dyspnea, a patchy clouding on *x*-ray, extreme caution is needed in fluid adminis-

tration both pre- and postoperatively. All of these patients need oxygen, even at times under slight pressure though its efficacy has not been incontrovertibly proven. There were about six deaths from transfusion reactions during the year despite satisfactory cross-matching.

In the further preparation of these patients for surgery, *x*-ray examination of the abdomen for location of retained foreign bodies has been mentioned. When either a perforating wound or the portion of the retained foreign body indicated that the missile has crossed the pelvis, proctoscopy or sigmoidoscopy should be done to determine if any perforations of the rectosigmoid have occurred. The presence of fresh blood may be noted at times when the actual perforations are not visible. It has not been an uncommon finding at abdominal operation to find the wound tract extraperitoneal; but if the rectum has been perforated, colostomy must be performed. The knowledge of the perforations must of course be obtained prior to laparotomy. Similarly, all patients should have a urinalysis if there is any possibility of injury to the urinary bladder or kidneys.

ANESTHESIA

It has been the general experience that ether anesthesia has been the anesthesia of choice on these patients. If recently shocked, they tolerate spinal very poorly. If there is any chance of diaphragmatic involvement, intratracheal anesthesia is indicated. In reviewing the first 10,000 anesthetics of our hospital after landing in Normandy, it was found that 40 per cent of the ether anesthetics were intratracheal. The presence of a pulmonary blast injury contraindicates an ether anesthesia, as several times pulmonary edema has followed such an error when the presence of the blast effect was not previously recognized. Under such circumstances, and at times when pulmonary complications as atelectasis, or perhaps just general toxicity or extensive injury seem to contraindicate a general anesthetic, bilateral intercostal block from T 6 to 12, supplemented with local infiltrations of the operative site, may be used and has proved satisfactory a number of times for our unit. At this point a word of caution is indicated concerning routine preoperative or preanesthetic medications. Very severe respiratory depression has been repeatedly experienced in severely shocked patients who have received several injections of morphine during evacuation, while at the same time not absorbing it due to their shocked condition. The supportive measures used in their preoperative treatment may bring them out of shock, thus improving their circulatory condition and producing a sudden absorbtion of the subcutaneously accumulated dose with the very distressing depressant respiratory effects, resulting in an anoxia which is definitely harmful to the patient. Immediate postoperative aspiration of the tracheobronchial tree, either through the intratracheal tube or by direct bronchoscopy seemed to reduce the incidence of postoperative atelectasis, which was much greater in incidence after laparotomies than after thoracotomies; the latter group were almost routinely bronchoscoped immediately postoperatively.

OPERATIVE MANAGEMENT

Incisions. In deciding upon the approach to be used the course of the missile, if known, will greatly influence the decision. A rectus or paramedian incision of adequate length over the side suspected of the major portion of damage will give adequate exposure. In injuries involving the spleen, splenic flexure of the colon and left renal area, as a perforating wound in the hypochondium from front to back, a subcostal incision has often proven very adequate. Small diaphragmatic perforations may be repaired from this approach as well. However, when one is faced with a thoracoabdominal wound on the left in which the course of the missile as determined has been confined to the upper outer quadrant of the abdomen involving probably the spleen and diaphragm, transthoracic (ninth

rib) transdiaphragmatic approach (under intratracheal anesthesia) has allowed repair of the injured lung, splenectomy with ease when indicated, as well as repair of the splenic flexure of the large bowel and inspection of the stomach and upper small bowel. When the course of the missile has been from the chest into the abdomen, we more often performed our surgery through the abdominal approach. The reverse course of the missile was more likely to leave an open pneumothorax at the wound of exit and already caused considerable pleural contamination so that in this type the transthoracic approach was almost mandatory. In general, the operative incision should be through the site of election, and the missile wounds treated only as such, i.e., débrided, peritoneum and deep fasia closed, while superficial closure may be attempted in clean wounds or the placement of sutures for secondary closure in a few days may avoid deep troublesome infection.

MANAGEMENT OF SPECIFIC INJURY

Hemorrhage. When the abdomen is first opened, the presence of blood in any amount will require first the determination of the source of bleeding and its control. Patients often times will make a markedly favorable response to their shock therapy following control of the bleeding. The routine examination includes the spleen and liver and mesentery of the intestine, severed vessels in the latter often causing very marked losses of blood. Wounds of the stomach and upper small intestine are often times associated with severe hemorrhage. If examination of these possible sources fails to reveal the cause, hemorrhage from injuries to major retroperitoneal vessels must be considered. The author recalls several very striking examples of the latter. The first of these occurred in Southern Tunisia in a soldier with a penetrating wound of the back. In the early days of the campaign suction apparatus was not available except as ingenuity furnished and in this case the abdomen was filled with blood. Removal by large sponges could not keep up with the flow, and rapid spleen, liver, gastric, and mesenteric examinations were negative. Exploration of the lesser omental cavity from which the bleeding seemed to stem revealed the source as behind the middle superior edge of the pancreas, apparently due to transsection of the splenic vein. Another example revealed the source to be the right common iliac vein which was controlled by extraperitoneal ligature through a separate inguinal incision. Another time the persistent bleeding was coming from a hole in the posterior peritoneum from a major vascular injury of the renal pedicle necessitating nephrectomy. Thus, upon opening the abdomen, control of hemorrhage is the first consideration.

Spleen. Major wounds of the spleen require splenectomy. Occasionally, bleeding seems self-arrested and exploration shows a superficial crease of the spleen. We have repeatedly treated these conservatively if small and no longer bleeding and have known of no ill effects therefrom. This has been reported by Imes[1] as well.

Liver and Diaphragm. In the case of liver lacerations, if large, we have used a heavy catgut suture on an atraumatic needle for deep mattress sutures with packing of any areas of stellate injury or tissue loss, and always drained by penrose drain through a stab wound. While the author was making an official follow-up tour of general hospitals in England during the lull in the fighting in the Fall of 1944, he came across one case in which the drains in such a case had been removed at ten days and the patient developed a bile peritonitis four days later. Although unduly long retention of packing may produce secondary adhesive effects (it has produced secondary intestinal obstruction requiring operation) an adequate escape route should undoubtedly be maintained for drainage of bile for about two weeks.

Although properly belonging under discussion of thoraco-abdominal wounds, if

at abdominal exploration a wound of the diaphragm over the liver is found, it should be closed and subphrenic drainage instituted. The usual approach for this type of wound will be transpleurally with repair of the diaphragm and subphrenic drainage through a subcostal stab wound with closed intercostal catheter temporary pleural drainage. If this is not done, a thoraco biliary fistula will almost always result necessitating later open thoracotomy, repair of the diaphragm and subcostal subphrenic drainage. It is also quite evident that in any thoraco-abdominal wound approached through the abdomen, the diaphragm should be primarily closed after control of any hemorrhage. An open diaphragm subjects the patient to the same shocking disturbances of respiratory physiology that occurs in an open pneumothorax. The diaphragm should be routinely examined in exploration of wounds of the upper abdomen.

Before considering specifically the wounds of the gastrointestinal tract, a few more words of discussion about liver injuries is needed. In the author's unit, of 457 wounded with primary abdominal wounds brought to the hospital, forty did not receive laporotomy. The mortality in this group was 5 per cent, mainly embolic in origin. Over half of these cases were small penetrating wounds of the liver with missiles of 1 cm. or less in size having entered the liver substance through the posterior, lateral or high anterior approach, the position of the foreign body, if retained, being within the liver substance. The known tract of the missile precluded pleural or other abdominal visceral injury. In these cases, conservatism may be used under constant vigilance to recognize early biliary drainage into the abdominal cavity which will of course require laporotomy. The question of removal or retention of foreign bodies will be discussed separately later.

Pancreas. Wounds of the pancreas have occurred in only moderate frequency, and repair of the capsule and establishment of external drainage has adequately taken care of them. Pancreatic fistulas were distinctly unusual, and digestion of the skin about the external wound has often failed to occur or been very minimal.

Stomach. Wounds of the upper gastrointestinal tract are often associated with considerable hemorrhage, especially gastric wounds. If one finds an intestinal perforation, he must seek a second one, as the foreign body with rare exception passes through the hollow viscus and, therefore, there must be both a wound of entrance and exit. In examining the abdomen, after incision and control of hemorrhage, a routine of exploration should be adopted. In our unit, this has generally been first the small and then the large bowel. If a large rent is evident to decrease spillage on Allis clamp or two is immediately used to approximate the defect and reduce the spillage; especially in large intestinal lesions has this seemed particularly indicated. In perforating wounds of the stomach, one wound is frequently posterior and opening of the gastrocolic omentum will more often be necessary to discover and repair the posterior wound. In closing gastric wounds, if two ragged holes present in close proximity, the quickest repair will be accomplished by uniting these into one large simple opening and then closing it transversely to the axis of the stomach. A running suture of chronic catgut through all layers followed by an inverting seromuscular (Cushing or Lembert) suture of atraumatic catgut or No. 3 silk has been used, a few interrupted reinforcing sutures of silk finally being placed. A Connel type of suture has also been quite satisfactory at times and insures inversion of the suture line. Interrupted sutures have not been used generally as multiple wounds are the rule in these patients and time for repair must definitely be gauged and conserved.

Duodenum. Wounds of the duodenum have fortunately not been too common, but have a high incidence of complications, especially breakdown of the repair,

localized abscess, generalized peritonitis or duodenal fistula. If the duodenum is open, the result of injury, the position of the ampulla with relation to the intestinal wound should be determined. If any of the retroperitoneal portion of the duodenum has been involved, the incidence of complications, repeatedly fatal, has always been high. It is probably a safer procedure, if loss of duodenal substance is extensive or technical difficulties are otherwise too great, to complete a satisfactory anastamosis to close the open duodenal ends separately and perform a gastro-enterostomy, with prophylactic penrose drains down to the area where any possible duodeno-biliary leakage that may occur. Drains must, of course, be kept away from the immediate location of suture lines. By incision of the lateral peritoneum where the duodenum becomes retroperitoneal, more adequate exposure may allow repair. A drain posteriorly or laterally if the retroperitoneal area has been involved in the wounding would seem advisable. Small duodenal wounds may be satisfactorily closed by purse-string suture, reinforced by a second row of interrupted sutures.

Jejunum and Ileum. In wounds of the jejunum, due to the relatively larger size of this portion of the intestine as compared to the ileum, one can generally perform the obvious type of repair without fear of secondary obstruction. If several perforations are located in close proximity to each other, it is simpler and quicker to join them by cutting, converting the wounds into a single one which may then be closed by a simple line of suture (usually two layers) with its line transverse to the direction of the bowel. In the author's unit, a double row of running chromic catgut with the inner through all coats and the second only seromuscular, proved routinely satisfactory. Occasionally, the second row was made with silk when atraumatic catgut sutures were not available. Not infrequently numerous multiple perforations may occur within one small segment of the bowel. Under these circumstances, resections of the involved area may save considerable time and avoid constriction of the lumen that might follow attempt to suture individually all the perforations if quite a few are all located within a very small segment. Traumatic transsections of the bowel may be repaired by an end-to-end anastomosis in the jejunum. In the ileum, due to the smaller lumen, closure of the ends and side-to-side anastomosis has proved more feasible. When the ileal transsection is incomplete, the mesenteric portion has often been uninjured and an end-to-end anastomosis has proved feasible. In our experience,[2] multiple intestinal injuries have occurred ten times as frequently as single perforations. Despite routine examination of the entire small bowel by all operating personnel, small intestinal perforations were missed three times, twice in abdominal explorations and once in a transthoracic exploration of a thoraco-abdominal wound. As exceptions to the rule, two of these came to postmortem at a later date and proved to be tiny lacerated wounds.

Colon. In handling wounds of the large bowel, the principles of management differ somewhat. Frequently in patients very severely injured and in whom a minimum operative procedure is indicated a simple exteriorization as a loop colostomy of the wounded portion will be all that can be done. When colon wounds are primarily closed and dropped back, a high incidence of secondary suppurative intra-abdominal complications has occurred, along with secondary breakdown of the suture line. When the perforation is so located that exteriorization would greatly increase the operative work, as extensive mobilization in the case of flexure wounds, or otherwise as in low sigmoid wounds in which exteriorization is not feasible, a proximal decompressive procedure as a transverse colostomy or cecostomy has been used. Wounds of the cecum or low ascending colon can be exteriorized as a cecostomy.

If soilage of the abdominal cavity has been considerable about the colon wound, a penrose drain through a stab wound from the usual sites of collection seems to lessen the incidence of postoperative abscess. In the case of splenic flexure wounds when splenectomy has been necessary, the incidence of secondary subphrenic abscess has seemed notable. This has occurred at least three times in the author's unit, each time fortunately responding to drainage. The type of colostomy to be performed either for decompressive purposes or for exteriorizing the wounded segment has had a varied vogue. In the fall of 1944, the spur type was requested by the general hospitals in England. However, retraction of the loops, secondary interpositions of small intestine and frequent inability to mobilize enough bowel when exteriorizing wounded segments near the flexures led to so many secondary difficulties in closing these wounds in the general hospitals that early in 1945, a request was made for simple loop colostomy with the usual longitudinal incision of the anti-mesenteric surface for opening. It was found that subsequently in the general hospitals, these could be closed and dropped back into the abdomen with a very low incidence of infectious complication, the previous heavy vaccination of the peritoneum at the time of original injury having developed an appreciable degree of immunity.

In the case of small single perforations of the large bowel, the author has a number of times closed them but exteriorized the affected portion as a simple loop. After three days the supporting rubber tube used beneath the loop was removed if the suture line appeared to be healing, thus dropping the loop back somewhat into the wound. These repairs were successful in selected cases in about 90 per cent of the cases and allowed the healed loop to be dropped back into the abdomen in about two weeks, thereby shortening the patient's hospitalization considerably.

Rectum. One finally comes to the last portion of the intestinal tract, the extraperitoneal rectum. Wounds traversing the pelvic girdle may perforate the rectum and be extraperitoneal. Proctoscopy is mandatory in any suspected wound of this type if its presence is not definitely known. When it occurs a sigmoid colostomy of the spur type isolating the distal bowel segment is indicated. The rectal wound should be drained by thorough débridement of the wound tract, and in addition drainage of the infraperitoneal and pararectal spaces by posterior midline incision down to the coccyx and through the fascia propria. When external drainage of these perirectal infected spaces is not instituted, nor colostomy performed proximally, spreading infection, abscesses and sinuses result. Hugh necrosis and infection of the gluteal muscles may follow, if the wound tract leads through this area. Coccygectomy and repair by suture of the perforations has been frequently advocated. Osteomyelitis of the sacrum[3] (Colcoth) has followed coccygectomy; and when the perforations of the rectum have been tiny, they have frequently healed without fistulas or complication if the fecal stream has been completely diverted and the infraperitoneal space simply drained[4] (Croce, Johnson, and Wiper).

The closure of colostomies in general has followed standard technics of preparation and closure when the original colostomy has been free of complications. Many times in the ETO, however, the author found during a tour of general hospitals, the tight retracted colostomy loops have necessitated a formal intra-abdominal approach and anastomosis which, as mentioned earlier, was found to be surprisingly successful. In the initial operative creation of the colostomy, they should be kept away from the exploratory incision and if possible from any compound fractures, as especially the ilium, as in the former case, wound infection and dehiscence and evicerations have not been infrequent, and in the latter, osteomyelitis has been a distressing complication.

Gallbladder. Wounds of the gallbladder have not been mentioned. These occurred

only about a half dozen times in the series observed, and simple closure if possible and drainage of the surrounding fossa has proved adequate several times. If extensive damage, cholecystostomy or cholecystectomy may be required, depending on the degree of damage. All wounds of the biliary and urinary tract were drained.

Urinary Tract Wounds. Before abdominal exploration, a urine specimen should be checked for hematuria. If present, it usually originates in either a wound of the kidney or the bladder, as wounds of the ureters have proved a rarity below the pelvis of the kidney. The author can recall only one in the series followed. If the bladder has been involved, the perforation may or may not involve the peritoneum. If the peritoneum has not been involved an extensive edema of the posterior and inferior pelvic reflection over the bladder may be evident. In these cases, the bladder has been opened through an adequate incision and the space of Retzius freed up by blunt dissection, the latter being carried well down toward the base in low lateral wounds. An attempt to close the bladder perforation by a mucosal suture layer and a second muscular suture, has always been made. Following this the bladder is closed about a cystostomy tube. This should be brought out as high as possible from the bladder dome, that is cephalad, as cystostomy tubes brought out immediately over the symphysis pubis have frequently resulted in secondary erosion and infection of the latter. Some perineal wounds may pass just beneath the bladder and sever the posterior urethra. We have used a mushroom catheter, preferably a Foley bag, which was threaded on to a urethral sound first guided up into the bladder in retrograde fashion by palpation with the finger in the bladder urethral orifice, the catheter serving as a splint for the urethra. Adequate débridement of the external bullet wound, usually near the perineum may serve for external drainage; but if there is any evidence of urinary extravasation, adequate perineal drainage should be instituted. In the author's unit, one patient explored for a perforating wound was found to have multiple small intestinal perforations which were repaired. The wound of entrance had been low in the abdomen and at surgery was noted to be near the dome of the bladder. Catheterized urine was negative and the bladder was not explored. Three nights later during a heavy rush period the patient developed markedly increased abdominal distention and after being unable to void was catheterized. Over 2,500 cc. of blood tinged urine was obtained and the abdominal distention seemed lessened. However, the patient continued a downhill course and at postmortem it was found the bullet tract had severed the muscle of the bladder but not penetrated the mucosa. Apparently this ruptured later spontaneously into the abdomen with the unfortunate results that ensued.

Ureteral injuries have been notable for their comparative rarity. If location and type of injury prevents reimplantation into the bladder or attempt at repair over a ureteral catheter with external drainage, an external ureterostomy (cutaneous) should be done as a temporary measure for reconsideration later as to further reconstructive surgery.

Wounds of the kidneys were generally treated quite conservatively. If examination of the wound suggested a perforation by a tiny missile and physical examination showed no evidence or signs of retroperitoneal irritation, débridement of the wound was all that was done. If the wound was appropriately situated, a penrose drain was frequently inserted. However, if the size of the missile and its known course indicated the possibility of major renal damage, the kidney was explored. Fragmented kidneys were removed as well as those with the pelvis of the kidney shot away. The author recalls a case of multiple intestinal wounds resulting from land mine fragments in which exploration of a posterior abdominal perforation through which

large amounts of blood were flowing into the abdominal cavity revealed the source as the renal pedicle. Ligation of the pedicle was necessary for control so the kidney was removed through the anterior wound, the posterior peritoneum closed and the retroperitoneal space drained posteriorly. This worked very well. If the kidney is removed through the peritoneal cavity, we have always used a retroperitoneal drain and closure of the posterior peritoneum. We have removed the kidney several times transpleurally (transdiaphragmatically) when injured severely along with the spleen, diaphragm and lung. Subcostal incision has worked well as has the classical posterolateral incision. However, many times the associated intraperitoneal injuries make a separate or posterolateral approach impractical for handling all the wounds encountered.

POSTOPERATIVE MANAGEMENT

All patients with major intraperitoneal wounds were placed postoperatively on a régimé of gastric suction, vigilant fluid balance to maintain a minimum daily urinary output of over 1,000 cc., with total intake to 3,000 cc., using 5 per cent glucose and normal saline while the gastric suction remained in place, otherwise only 1,000 cc. of normal saline and the remainder 5 per cent glucose. At least 500 cc. of blood plasma was given daily to try to replace in part the metabolic protein loss of the patient receiving nothing by mouth; thereby retarding the development of hypoprotinemia and aiding wound healing. Vitamin B_1 and vitamin C in doses of 10 mg. and 100 mg., respectively, daily were given intravenously. In the entire series there was only one wound disruption, and ileus was relatively rare. Sulfonamides were used routinely beginning with an early intravenous dosage of 5 Gm. of sodium sulfathiazole or sodium sulfadiazine and then 2.5 Gm. every eight to twelve hours as necessary to maintain an adequate concentration, while daily urinalyses and bi-daily blood counts were closely scrutinized for evidence of urinary precipitation of the drug (red cells or crystals) or depression of the hematopoetic system, either of which called for discontinuance of the drug. After a year in the Mediterranean Theatre, the unit entered France D + 4 in Normandy and penicillin was available for the first time. This was given in doses of 40,000 units every four hours though it is now accepted as being more efficatious if given at three-hour intervals. Although the latter drug aided wounds in general, it was difficult to say it changed our results as the postoperative mortality for the abdominally wounded in our hospital in the Mediterranean Theatre was less than that in the European. There are other factors, however, as heavier casualty reception, that can explain the difference.

Patients returning from a vigorous operative procedure were generally given oxygen by B.L.B. mask for twenty-four hours. This seemed of definite benefit. It was interesting to note that in our postmortem tissue sections as reported by the Army's Laboratory service, at times as high as 60 per cent showed microscopic if not gross evidence of blast injury in the lungs. The author has also seen repeatedly the postmortem finding of multiple epicardial and myocardial petechiac and ecchymoses in the heart where the known tract of the injuring missile has been over six or eight inches away. Transpelvic wounds where bony structures have been fractured have several times seemed associated with enough lateral transmission of the blast effect of the missile itself to produce these effects. Several times these findings have been limited to the diaphragmatic surface of the heart and the neighboring diaphragm. A word of caution should, therefore, be injected about the injudicious excessive use of fluids postoperatively if there has been any moisture in the lungs, hemoptysis or cyanosis. Ether anesthesia increases the pulmonary edema associated with the blast injury and the occurrence of a number of deaths from pulmonary edema several days postoperatively in patients who had not received over 2,500

cc. of fluids intravenously daily was a very disheartening complication.

Patients were started on a liquid, low residue diet with the return of normal peristalsis, the disappearance of distention and the passage of flatus.

EARLY COMPLICATIONS

Shock has been discussed. Postoperatively it still accounted for a very considerable number of deaths in the first twenty-four hours. Its treatment has been discussed. Blood was used liberally, precautions being taken to detect blast injury effects. The use of serum albumin seemed to be of definite though limited value.

Pulmonary edema has already been mentioned. Concentrated serum albumin in 100 cc. vials was available during the last two years of the war and this proved a very definite adjunct to the treatment of pulmonary edema in the early stages but was ineffective in the more marked cases. Positive pressure of oxygen seemed to accomplish no more than oxygen by the B.L.B. mask.

Pulmonary embolus accounted for a considerable share of the deaths. In the author's unit one soldier at postmortem had massive clots and thrombi filling the main pulmonary vessels. The source was found to be venous thrombosis about a retained foreign body in the flank about which some abscess formation had occurred. Prophylaxis against this complication was attempted by deep breathing exercises, frequent turning of the patient in bed and encouragement to move his extremities. Anticoagulants were not available, nor heat cradles for the lower extremities, as a mobile hospital unit must conserve in equipment and expenditure of electricity which it has to manufacture itself.

Pulmonary complications, especially atelectasis, was relatively common postoperatively during the colder months. The incidence was higher in the abdominally wounded than in our thoracic cases, many of the latter being routinely bronchoscoped at the close of the operative procedure. Had this been done with the abdominally wounded, the morbidity of this complication might have been lower.

Peritonitis and secondary abdominal abscesses must be watched for. Under our present day chemotherapy the signs and symptoms are very often masked. We had one patient with a closed abdominal injury with a five-day ruptured sigmoid colon, come in with a soft abdomen only to go on to distention and death from generalized peritonitis. Abscesses were most commonly found in the pelvis, subphrenically on the left, subhepatically on the right and in the epigastrium in the vicinity of the upper greater omentum, on in the lateral "gutters." Several patients developed pelvic abscesses while in our institution. All but one were drained surgically, the other evacuating spontaneously into the rectum. The pelvic abscesses were more often drained under local anesthesia. Subphrenic abscess on the left several times followed splenic flexure injuries in which splenectomy had also been necessary. Drainage in all resulted in early recovery.

Small intestinal obstruction occurred in the early postoperative period about a dozen times. Three required surgical intervention while the remainder responded to introduction of the Miller-Abbott tube. This was passed under fluoroscopic control, the passage through the pylorus frequently requiring repeated observation at twenty to thirty minute intervals. Two cc. of mercury in the inflatable balloon considerably shortened the procedure.

LATE COMPLICATIONS

Transportation under ten days postoperatively was fraught with danger and evisceration not uncommon in the early days of the war. A routine theatre order later required through-and-through stay sutures, and this greatly reduced the incidence of this distressing complication. Wounded, suffering from mild respiratory infections when hit have an increased incidence of pulmonary complications attended with the inevitable cough. If

they became hypoprotinemic or are suffering from relative vitamin deficiency, evisceration may be more often anticipated.

Amongst late complications as seen in the general hospitals (during tour of hospitals in England) was some form of sequellae to improper colostomies. This has been referred to earlier. When the loops of the colostomy were under tension, inflammatory reaction about them not infrequently caused the loops to retract below the surface of the abdominal wall with abscesses of the abdominal wall and fistulas. Gangrene of a colostomy loop may also occur if tension is sufficient to interfere with its blood supply. When colostomies were brought out the abdominal exploratory wounds, and secondary infection occurred, as it more often did, small bowel fistulas were not an uncommon additional complication, in addition to breakdown of the wound itself the result of unavoidable gross infection.

Pleural complications following liver or left-sided kidney wounds usually result from a transdiaphragmatic wound of the respective organ where, the diaphragm may or may not have been repaired but no external subphrenic drainage was instituted. Transpleural repair of the diaphragm after first placing a subphrenic subcostal drain through a stab wound from within out (while the diaphragm is open) with closed intercostal pleural drainage seems the only way to avert a chronic pleurobiliary fistula and chronic empyema.

The question of the removal of retained foreign bodies is always perplexing. One example was given of the fatal complications following retention of a sizable one with subsequent abscess formation. In many instances they cause no further trouble but larger ones can usually be located by careful search if within the abdomen. Retained foreign bodies in the liver are more often quiescent but occasionally produce an abscess which eventually ruptures into the subphrenic space. Prophylactically, if a large foreign body is thus known to be retained, the leaving of the drain in place a little longer might avoid a subphrenic abscess. One case of bile peritonitis was reported in England fourteen days after wounding and four days after removal of a drain following injury to the liver.

Secondary intestinal obstruction has also occurred as a late complication. One general hospital reported an incidence just under 25 per cent with half of these requiring secondary operation. This figure, however, was greatly above the general incidence of this complication.

SUMMARY

An attempt has been made to relate the lessons learned in the management of over 500 war wounds of the abdomen treated on the author's service in an evacuation hospital overseas. Opportunity to follow up a varying number of these cases and similar one's was afforded at the close of several of the campaigns and included an officially sponsored follow-up tour of general hospitals in the ETO treating these cases in the later phases of their care. Complications which may occur have been mentioned. The late care of colostomies has been only mentioned as their care and closure when properly constructed initially follows standard surgical procedures. The importance of early supportive treatment, especially transfusion with whole blood has been stressed and the need for stabilization of the circulatory system, especially if continued hemorrhage has been excluded before undertaking surgery has been emphasized, being even more important than the time preoperatively. The value of intratracheal anesthesia has been discussed. Finally the complications to be looked for have been recounted.

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PERFORATING WOUNDS OF THE COLON AND RECTUM*

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IN the opinion of the majority of surgeons responsible for the primary surgery on the more severe types of battle injuries in the Mediterranean Theater during World War II, perforating wounds of the abdomen made greater demands on the skill and experience of the operating surgeon than wounds of any other part of the body. This was true even of those surgeons whose training had been largely in abdominal surgery and who might have been expected to have more difficulty with perforating wounds of the chest, head or extremities, all of which, of course, they were called upon to treat whenever the flow of casualties was heavy. Of the various viscera which might be injured in wounds of the abdomen, none presented more serious problems from the standpoint of mortality, morbidity and the exercise of correct surgical judgment than perforating wounds of the colon and rectum.

With this in mind it might be of interest to review an experience with 120 patients admitted to the wards of a general hospital in the Mediterranean Theater with perforating wounds of the colon or rectum. They have been divided into two groups: The first twenty-five were admitted during the winter of 1943 to 1944 and represented casualties occurring early in the Italian campaign. The second group of ninety-five cases was admitted between October 9, 1944, and January 15, 1945, after having been operated upon by forward surgeons, most of whom had then had one and a half to two years experience operating in the advanced field and evacuation hospitals.

GENERAL PRINCIPLES

The primary objective in the treatment of perforating wounds of the colon just as in the treatment of battle wounds of any other type is the preservation of the patient's life. To accomplish this in as high a percentage of patients as possible, three fundamental principles must be kept in mind: First, the perforation must be dealt with in such a manner that a further leakage of intestinal contents into the peritoneal cavity is prevented; second, the manner of closure must be such that there is no marked impairment of the bowel lumen, and last, the procedure should be one that will add a minimum of shock to a patient already suffering from exposure, loss of blood and the trauma of a severe wound. The colon wound is usually associated with multiple wounds of the small bowel and other abdominal viscera and often with wounds of the extremities, perineum, buttocks and other parts of the body.

That marked progress toward this primary objective has been achieved is shown by a comparison of the mortality figures of patients with perforating wounds of the abdomen operated upon during this recent conflict with the mortality figures for similar groups of patients operated on during World War I. Then the mortality rate ranged from 50 to 75 per cent. In this war it has dropped to the neighborhood of 30 per cent. This includes those dying in the general hospital sometimes weeks after their injury, and is a tribute to the Medical Corps of the Armed Forces of the United States. It is the result partly of the early and adequate replacement of blood loss. It is frequently necessary to give blood to those patients in amounts as high as 3,000 to 4,000 cc. during the first twelve hours. It is also partly the result of the extensive use of the sulfonamide drugs

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and penicillin, both intraperitoneally and parenterally. More than either of these factors, it is due, I think, to the high degree of technical skill employed by the surgeons operating in our forward hospitals. In my opinion, the development of the highly trained surgical team consisting of surgeon, assistant, anesthetist and surgical nurse, often augmented by a medical officer trained in the treatment of shock, is one of the most significant advances made in the field of military surgery during this war. The widespread use of such teams in the field and evacuation hospitals, operating usually within a few miles of the front lines, has saved many battle casualties which a few years ago would have been considered hopeless from the standpoint of military surgery.

As the mortality decreased, it became possible to concentrate on a secondary objective, namely, to decrease the high morbidity associated with these wounds. All too often, separation of the laparotomy incision, retraction of the colostomy and the formation of intraperitoneal and subphrenic abscesses followed the successful primary treatment of the wound. Frequently, these complications were sufficiently serious to jeopardize the life of the patient.

Exteriorization of the injured segment of the colon has become an accepted principle in the treatment of the majority of perforating wounds of the large bowel, yet in 28 per cent of the first group of twenty-five cases the colostomy stoma was at the level of the skin or beneath when the patients were admitted to the general hospital. In 25 per cent of this group abscesses of the abdominal wall, adjacent peritoneal cavity or subphrenic space occurred. One patient whose original operative note mentioned that the segment of colon had been exteriorized with some difficulty, was admitted with a markedly retracted colostomy, pouring feces into a widely separated wound and the adjacent peritoneal cavity. The following series of major complications developed: extensive abdominal wall abscess, left pericolic abscess, right pericolic abscess, large right pleural effusion, right subphrenic abscess, massive left pleural effusion, left subphrenic abscess, and finally empyema of the left pleural cavity. He represented a serious diagnostic and therapeutic problem for weeks and nearly succumbed on several occasions. He did not make a sustained improvement until the last abscess had been drained, in spite of extensive chemotherapy, penicillin and supportive treatment.

It is obvious that the bowel must not only be exteriorized but it must be exteriorized without tension. If there is any tension on the exteriorized segment, it will inevitably retract regardless of the type of support which is used to hold it above the skin. Exteriorization without tension as well as the formation of a spur of adequate length, if such a spur is desired, is dependent on adequate initial mobilization of the bowel. By incising the line of fusion between the visceral and parietal peritoneum, and mobilization of the mesentery of the bowel to its central attachments on the posterior abdominal wall, it is possible to exteriorize any segment of the colon, terminal ileum or sigmoid at some point on the abdominal wall without tension. Since all of this dissection is in a relatively avascular area, it can usually be carried out within a few minutes. (Fig. 1.) In mobilization of the right colon, the right ureter and the retroperitoneal portion of the duodenum must be identified, reflected posteriorly and preserved. On the left side care must be taken to reflect the left ureter as the dissection is carried medialward; and if the splenic flexure is to be liberated, the jejunum at the ligament of Treitz should be identified and preserved. Upon the completeness of this initial step a great deal of the success of the entire surgical procedure depends.

As experience increased and the problems of the forward surgeons were correlated with those of the men caring for these patients in the general hospital to which they were evacuated, a decrease in mor-

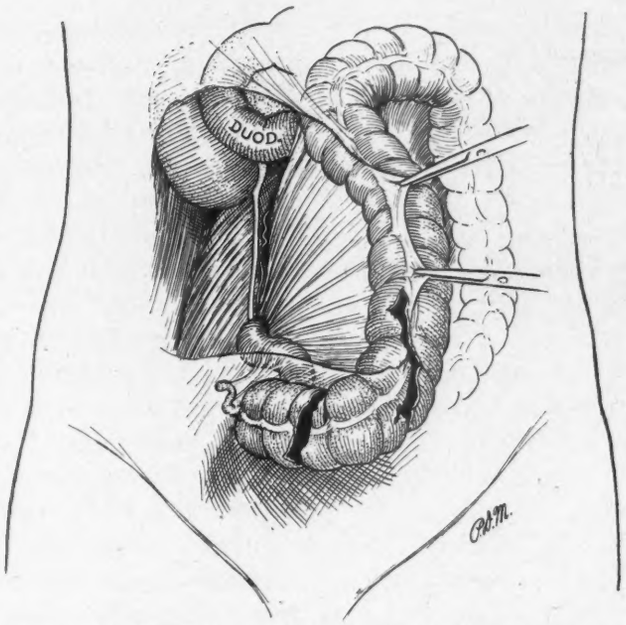

Fig. 1. Mobilization of the terminal ileum and ascending colon. As the dissection is carried medialward the right spermatic artery and vein come first into view. The right ureter will be found just medial to these vessels. At the upper end of the field the retroperitoneal portion of the duodenum will be exposed and must be carefully reflected posteriorly.

bidity occurred comparable to that in mortality. In this last group of ninety-five cases only 11 per cent had retraction of their colostomy to the level of the skin or beneath and only two of these patients had associated abscesses, one of the abdominal cavity and one of the right subphrenic space.

Double barrel colostomies with loops crossed in the form of an "x" and other irregularities which were occasionally seen in 1943 were not found in this last group of patients. No patient in this group was evacuated to the United States with his colostomy not closed because of technical difficulties arising from errors in its construction. In order to decrease as far as possible the high incidence of laparotomy wound suppuration and separation in these cases, the colostomy was routinely brought out through a separate lateral, muscle-splitting incision. In spite of this and other measures, in 10 per cent of this last group of cases there was separation of the wound down to the peritoneal level, and in three per cent it was complete, exposing the peritoneal cavity. However, in five of these ten patients, including all of the complete separations, the separation was due to a strangulating type of figure-of-eight retention suture which produced slough of the entire fascial suture line in each case.

The essential objectives and fundamental principles of surgery of the colon following battle injuries are the same as those underlying surgery of the colon in peace time. The method of carrying out these principles and obtaining these objectives may necessarily vary considerably. It will vary with the type of injury concerned and may properly within limits vary with the individual surgeon.

WOUNDS OF THE CECUM AND ILEOCECAL VALVE

There were nine cases of this type in the last series of patients. If the wound is small and involves the anterior or lateral wall of the cecum, mobilization of the cecum and exteriorizing the injured area offers a simple way of treating the perforation. If the perforation itself can be exteriorized it will not only avoid the possibility of intraperi-

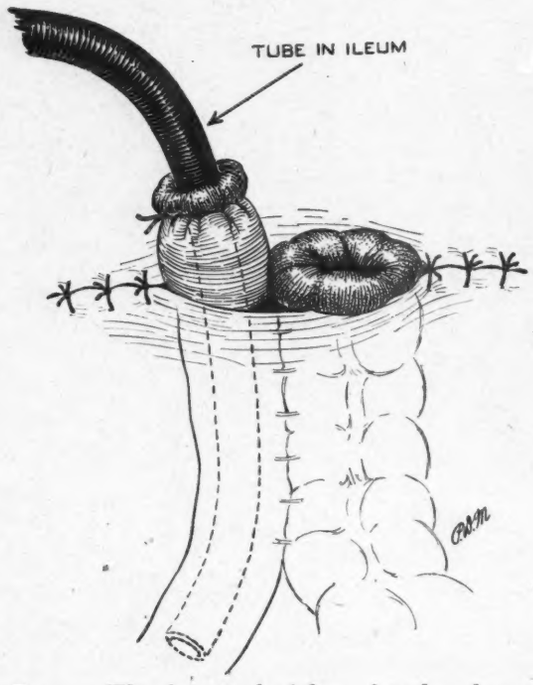

FIG. 2. The lacerated right colon has been removed and a double barreled ileocolostomy formed. After the dressings have been applied to the wound a large rubber tube is placed in the terminal ileum for immediate decompression, and soiling of the dressings and wound prevented by a tight ligature around the staggered, devitalized terminal ileum and tube.

toneal leakage, but a cecostomy of this type is definitely superior to the average tube cecostomy from the point of view of function. A well functioning cecostomy is particularly desirable if one elects to close by suture a perforation in the region of the ileocecal valve or in an area of the cecum not easily exteriorized. If a perforation of this latter type can be securely closed without impairment of the lumen of the terminal ileum, it is frequently possible to avoid a major surgical procedure by closing the perforation and providing a safety valve with the establishment of an adequate cecostomy at the point of election in the anterior lateral wall of the cecum.

It is with extensive injuries of the terminal ileum, cecum and lower ascending colon in which repair cannot be accomplished without undue risk of either leakage or obstruction or both or in which the destruction is so extensive that resection is the only feasible course that a difference of opinion has arisen. I believe that the procedure of choice is mobilization of the right colon and terminal ileum, exteriorization and resection of the injured segment and the construction of a double barrel ileocolostomy spur consisting of the proximal uninjured ascending or transverse colon and the terminal ileum. (Fig. 2.) It is considerably less time-consuming and less shocking to the patient than exteriorization or resection of the injured segment, and side-to-side or end-to-end anastomosis of the ileum and transverse colon. This may be of vital importance if one is dealing with multiple injuries as is so often true in these cases. It also eliminates two hazards which must always be present when this latter procedure is carried out, namely, leakage or obstruction at the site of the anastomosis. The double barrel spur can be clamped on the seventh or eighth day following the operation, with prompt diminution in the amount of liquid discharge from the ileum and a rapid improvement in the appearance of the surrounding skin and of the patient.

The possibility of a high incidence of sepsis and separation of the colostomy incision because of the presence of the open ileum with its irritating liquid content has been raised as an objection to this procedure. This did not occur in the six patients who came under my care nor has it occurred in a rather considerable experience with an almost identical procedure used in the treatment of carcinoma of the cecum in peace time. The laparotomy wound should, of course, be protected against contamination by bringing the ileocolostomy out through a lateral, muscle-splitting incision. This has become an accepted principle of war surgery whenever a segment of bowel is exteriorized. If desired, a large rubber tube can be placed in the terminal ileum, held in place by a ligature or purse-string suture, and connected to a bottle at the side of the bed. This will usually function satisfactorily for four to five days, with little or no soiling of the colostomy dressing. (Fig. 2.)

No complications have been observed as a result of the application of a crushing clamp to the ileocolostomy spur as early as the seventh or eighth day following operation, and each of these six patients was evacuated with his ileocolostomy closed, bowels functioning normally and with no weakness at the site of the closure.

The only alternative to this procedure which has been recommended for severe wounds of the cecum and terminal ileum, apart from the seldom feasible primary anastomosis between the ileum and transverse colon with resection or exteriorization of the injured segment, is the establishment of a terminal ileostomy in the right lower quadrant and exteriorization of the proximal end of the colon below the costal margin following resection of the injured segment. Intestinal continuity is later restored by disconnecting the ileostomy, performing an anastomosis between the ileum and transverse colon, and then closing the colostomy. In my opinion, there are a number of objections to this procedure. In the first place, construction of a satisfactory terminal ileostomy is considerably more difficult than the construction of a satisfactory colostomy. A terminal ileostomy is difficult to fix securely to the abdominal wall so that retraction or prolapse will not occur. If either of these complications do occur, it necessitates an emergency surgical procedure in a patient who is in no condition to stand one. If the ileostomy does continue to function satisfactorily and the patient can be evacuated to a general hospital, he still remains a serious problem from a medical point of view. It is not advisable to subject these patients to the hazards associated with the evacuation of an ileostomy patient to the Zone of the Interior, and they require very careful observation even on the wards of a general hospital. They present a problem from the point of view of everyday nursing care because of the constant discharge of liquid or semiliquid ileal contents. The difficulty of maintaining adequate nutrition in patients with an ileostomy is well known, yet in these patients their nutrition not only must be maintained but it must be improved to the point where they will withstand another major surgical procedure to restore intestinal continuity.

In certain instances, in spite of the desirability of closing their ileostomy at the earliest possible moment, complications or associated injuries may make delay imperative. Lastly, the elimination of the ileostomy and the anastomosis of the ileum to the transverse colon, when it is carried out, may have to be performed in the presence of adverse intra-abdominal conditions which could increase considerably the risk inherent in this procedure. These patients have all had varying degrees of generalized peritonitis. Adhesions will not only be present but we have observed at postmorten actual collections of liquid pus in various recesses of the peritoneal cavity and between loops of small bowel as long as five or six weeks following their injury.

WOUNDS OF THE COLON FROM THE CECUM TO THE RECTOSIGMOID

The treatment of wounds of the upper ascending colon, hepatic flexure, transverse colon, splenic flexure, descending colon and sigmoid will depend largely on the extent and position of the perforation. If the perforation is relatively small, that is 1 to 3 cm. in size, and involves the antimesenteric aspects of the bowel wall, exteriorization of the injured segment as a loop colostomy offers a safe and quick method of treatment. As a rule, it presents no unusual difficulties with subsequent restoration of intestinal continuity, even though at the time of closure it is usually necessary to expose a considerable portion of the adjacent peritoneal cavity in order to reduce satisfactorily the exteriorized segment; and the possibility of some degree of peritonitis, should there be any leakage of the suture line, does exist. I believe that, in the future, the principle of exteriorization will be modified for wounds of this type and that most of these small and moderate sized wounds of the antimesenteric surface

of the bowel will be closed by suture and the bowel replaced in the peritoneal cavity at the primary operation. If the wound involves one-half or more of the circumference of the bowel or if it involves the mesenteric border, a somewhat different situation exists. Here the exteriorization principle is undoubtedly safer and if the wound involves the mesenteric border, it necessitates complete division of the bowel to obtain an adequately functioning colostomy. Here we have two segments of bowel almost or completely separated, one from the other. Exteriorization, with approximation of the two loops of bowel by one or two rows of sutures so as to form a double barrel Mikulicz spur, permits the subsequent restoration of intestinal continuity by means of a relatively minor extraperitoneal procedure. This type of closure can be carried out by any surgeon in the base hospital with no risk of peritonitis. (In most of the cases in this series closure was made under procaine field block anesthesia supplemented by a small amount of pentothal sodium intravenously.) If a spur is not constructed for one reason or another, intestinal continuity in these cases will have to be restored by end-to-end anastomosis or by closure which will come very close to involving the entire circumference of the bowel. This is a procedure which even in the hands of experienced colon surgeons will probably continue to carry an appreciable mortality and morbidity.

It is of interest to note that in two patients with severe injury to the bowel, impairment of the blood supply led to a secondary slough of the exteriorized segment. In each case one loop sloughed to the peritoneal level and the other beneath the skin surface. The two loops, however, had been approximated so that following the clamping of the remaining spur, extraperitoneal closure of the colostomy in each case was accomplished without difficulty, leaving ample lumen at the point of closure.

It should be emphasized again that regardless of what type of colostomy the operator elects to do, the bowel should be sufficiently mobilized so that it can be brought out well above the surface of the abdominal wall without tension. If a glass rod or rubber tube is being used to support a loop colostomy, for instance, the bowel should merely rest upon the rod or tube. If there is any downward pull, the colostomy will inevitably retract and the morbidity, if not the mortality, will be definitely increased. Among the eighty-four patients in this second group who were ambulatory and who had had their colostomies closed when evacuated to the United States, the only instance in which there was any fecal leakage from the colostomy wound following closure occurred in two patients whose loop colostomies had retracted. In one patient with an hepatic flexure loop colostomy, the stoma itself extended from the level of the skin through the abdominal wall down to the upper border of the liver. It had retracted and closure was made difficult because the hepatic flexure had not been completely released from its lateral parietal peritoneal attachments. A fecal fistula closed within four days, but the patient might easily have developed a right subphrenic or subhepatic abscess which would have prolonged his hospital stay considerably. The other occurred in a patient with a left lower quadrant colostomy in whom suppuration of the colostomy closure wound occurred secondary to osteomyelitis in the adjacent ileum. It also closed within a week.

PERFORATING WOUNDS OF THE RECTUM

It is generally accepted that there are two essential features in the treatment of a perforating wound of the rectum: First, the establishment of a colostomy, and second, adequate drainage of the perirectal space. It is also generally agreed that the colostomy should defunctionalize the rectum for that is the primary purpose of the colostomy. A difference of opinion arises as to what type of colostomy should be established. In my opinion, the vast ma-

sority of perforating wounds of the rectum can best be handled by mobilization of the jigmoid colon, complete division of the bowel at that point, and the approximation of the two sigmoidal loops by one or two rows of interrupted sutures to form a double barrel Mikulicz colostomy. Two objections to this view on perforating wounds of the rectum have been raised. It has been held by some that for severe wounds of the rectum, in order to defunctionalize the distal segment adequately, the bowel must not only be divided but brought out as two separate colostomies with a bridge of skin between the loops. I doubt if this is ever necessary except in those rare instances in which a large part of the rectal wall has been destroyed and a permanent colostomy must be considered. The amount of feces which will spill over into the distal segment from a double barrel Mikulicz spur with the bowel completely divided is negligible. It was not appreciable in any of the cases in this series and the rectal perforation healed satisfactorily in each instance. It must also be remembered that if the sigmoidal loops are separated, intestinal continuity will have to be restored by an end-to-end anastomosis.

The other objection that has been raised is that for small or moderate perforating wounds of the rectum, for questionable perforations of the rectum, for small perforations of the rectosigmoid which can be securely closed and for wounds of the perineum, a loop type of colostomy with an opening made on the antimesenteric border is perfectly adequate. (Fig. 3*a*.) This type of colostomy is said to be more easily constructed and will more readily permit the restoration of these patients to limited duty in an overseas theater.

Among these 120 patients, loop colostomy of this type for perforating wounds of the rectum proved far from adequate in defunctionalizing the distal segment, and whenever a slowly healing rectal or perirectal wound necessitated the existence of the colostomy beyond five or six weeks,

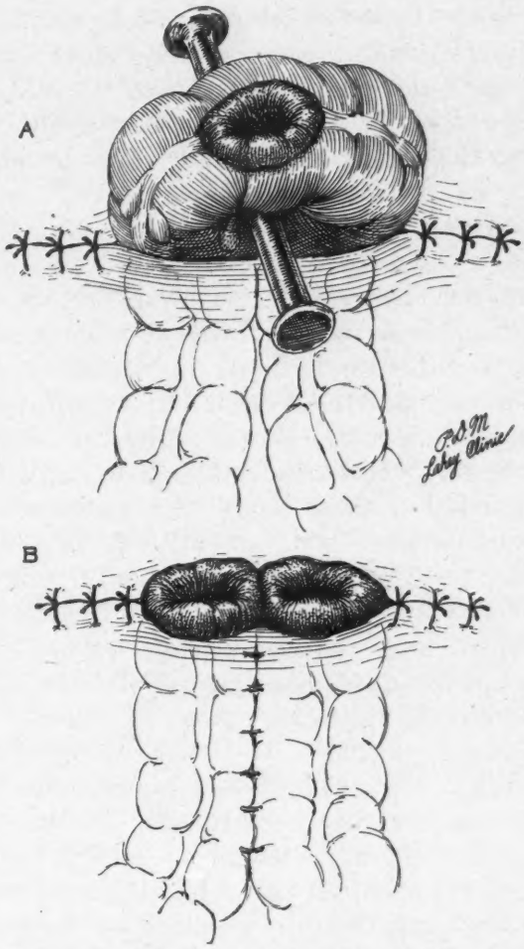

Fig. 3. A, a simple loop colostomy with incomplete division of the bowel. It will decompress but not defunctionalize the distal segment. If the limbs of the colostomy happen to fall fairly close together as shown, the bowel could be completely divided and later a crushing clamp applied to the spur, but great care must be taken that neither the mesentery nor loop of small bowel be caught in the clamp. B, double barreled Mikulicz type colostomy with complete division of the bowel. It will defunctionalize as well as decompress the distal segment and the spur can later be crushed, with no danger to mesentery or small bowel. It differs from A only in that the bowel has been completely divided between clamps and the antimesenteric borders of the two limbs united by six or eight interrupted sutures.

they showed an almost unanimous tendency to retract. Of the nine cases in this group in which a loop colostomy had been made for perforating wounds of the rectum, only one failed to accumulate feces rapidly or slowly in the lower rectal segment. In seven of the eight cases in which this occurred, the perforation remained unhealed eight weeks after the injury. Since in all

of these cases the colostomy was steadily retracting, permitting more and more feces to spill over, reconstruction of the colostomy had to be performed in order to keep the wound empty and secure healing of the perforation. The sigmoid was mobilized, the bowel completely divided and a double barrel Mikulicz spur constructed. Two conditions were present in each of these patients with non-healing of the rectal wound: First, an accumulation of feces inside the rectum and second, persistent suppuration in the perirectal wound in spite of adequate drainage. It may be argued that these loops were exteriorized under tension and undoubtedly in some cases this was true. Nevertheless, I believe there is a tendency for the partially divided loop colostomy, with no fixation except the glass rod originally placed under the bowel, to retract after a period of weeks.

When it is realized that mobilization of the colon is particularly easy in the redundant sigmoid region of which I am speaking and that the only additional step in the formation of a double barrel spur is that the two loops be left in sufficiently close contact that the adjacent walls can be crushed without injury to the mesentery or to the small bowel, it would seem that very little additional time or effort is required to construct this type of colostomy. It has frequently been possible to approximate the two loops by a crushing clamp and to do an extraperitoneal closure when the limbs have not been approximated by suture at all or when the limbs have been brought into close contact by approximating the ligatures on epiploic tabs. I believe that it is considerably safer and less painful to the patient when the clamp is applied if the antimesenteric borders are approximated by seven or eight interrupted sutures, uniting the adjacent longitudinal bands. (Fig. 3*b*.)

The problem of restoring these patients to limited duty depends largely on the type of individual concerned, the need for limited duty personnel in the theater, and the presence or absence of intraperitoneal injuries which might predispose to the subsequent development of small bowel obstruction, so frequently seen in patients with perforating wounds of the abdomen.

The muscle and fascia of the abdominal wall were carefully approximated following the closure of each of these two types of colostomy and no instance of herniation was observed at the time of discharge following the closure of either loop colostomy or double barrel spur colostomy. During 1943 and early 1944, when the need for limited duty personnel was most marked, several of the patients in the first group were restored to various types of limited duty, such as corpsmen in general hospitals, guards at stockades and clerks in base section headquarters. They were all patients who had had an extraperitoneal closure of a double barrel colostomy.

It is frequently difficult in these patients to be sure that the rectal perforation is a small one; and if the size of the perforation cannot accurately be determined, it would seem desirable to construct a colostomy which will keep feces out of that rectum as long as it may be necessary. For small wounds of the rectosigmoid which can be securely sutured and for wounds of the perineum a loop colostomy might be perfectly adequate, but here the question must arise as to whether a colostomy is necessary at all.

The only difference of opinion concerning the second essential point in the treatment of rectal perforations, namely, the drainage of the perirectal space, is as to whether or not it is necessary to remove the coccyx. There were seven patients in this group. in each of whom the coccyx was not removed at the time drainage was established. No instance of abscess formation as a result of inadequate drainage was observed, nor has it occurred in my previous experience with cases of this type in which the coccyx was not removed. The fundamental principle, however, is the adequate drainage of contaminated areas. If, because of the particular type of injury concerned

or because of limited previous experience with this type of injury, the operator believes that he cannot adequately drain the perirectal space without removal of the coccyx, he should by all means remove it. If, on the other hand, he believes that by dividing the fascia propria transversely at the tip of the coccyx, carrying the incision around into either or both of the levator ani muscles if necessary, then I think the coccyx is better left undisturbed.

It has been suggested that those patients in whom a draining sinus persists, leading down to the sacrum, are those in whom only a portion of the coccyx has been removed and the base has been left attached to the sacrum. If this proves to be true, disarticulation of the coccyx with removal of the articulating surfaces, as has been recommended, may eliminate this complication. The fact remains, however, that patients in whom the coccyx has been removed will henceforth have varying degrees of discomfort on sitting, and the projecting lower end of the sacrum may remain tender long after healing of the wound has occurred.

SUMMARY

In summary, in this last group of ninety-five cases there were thirty-six double barrel spur colostomies, fifty-five loop colostomies and four cecostomies. No instance of spreading peritonitis was seen after closure of the loop colostomy even though all were replaced in the free peritoneal cavity. No complications were associated with the clamping of the spur in the thirty-six double barrel spur colostomies. No patient required a secondary cecostomy following the closure of his colostomy, although in several patients with a loop colostomy on the left side, it was four to five days following closure before they were able to pass gas by rectum.

Eleven patients in this group were evacuated to the United States with their colostomies not closed. Seven of these patients had rectal wounds which were not healed five to six weeks following their injury. The other four were evacuated early because of an especial need for hospital beds at the time, and each had associated injuries or complications which made closure of their colostomies a secondary matter.

There were no fatalities in the first group of patients. In the second group there were four fatalities. One patient died suddenly shortly after admission from an exsanguinating hemorrhage due to a divided gastroduodenal artery which had been overlooked at the time the perforation in his duodenum had been repaired and the perforation in his hepatic flexure of the colon exteriorized. A second died seven weeks following his original injury from generalized peritonitis arising from a series of abscesses secondary to a retracted cecostomy. Two large abscesses in the right lumbar gutter were drained but a third gave rise to peritonitis from which he failed to recover. The third patient died from a pulmonary embolus following laparotomy for an intestinal obstruction ten days after his colostomy had been closed. The fourth patient died several weeks after his original injury from persistent suppuration in the retroperitoneal tissues. He failed to respond to penicillin, chemotherapy and drainage of the infected area.

CONCLUSIONS

Marked progress has been made in military surgery during the course of the recent war. The lessons learned must not be forgotten. The problems raised must be followed through and the best solutions possible be found so that the military surgeon of tomorrow may begin not where the military surgeon of today began but rather well beyond where he finished.

REHABILITATION OF THE INJURED HAND

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BUNNELL makes the statement that "Next to the brain the hand is the greatest asset to man, and to it is due the development of man's handiwork."

Certainly, during this last war man has perfected much varied and mechanized equipment all demanding some degree of manipulation by hand and this, in turn, has increased the incidence of hand injuries. The instinct to protect one's face and to use the hands to help one to safety in the face of danger also subject them to a greater probability of injury. Indeed, it is hard to conceive that a person could be injured in combat who would not receive, also, some injury to his hands due to this instinct to protect himself. Injuries due to these causes augment the large number of hand injuries sustained in combat as the result of direct enemy fire.

The incidence of hand injuries which have come under treatment on the Plastic Surgery Service of this naval activity is ever increasing. A comparative estimate on this service at any one time would reveal that between 20 and 25 per cent of the total number of cases are injuries of the hand in one form or another. In a paper of this kind it would not only be impossible but space would not permit a detailed discussion of each case of hand injury including the preoperative and postoperative care in its rehabilitation. For this reason, a general picture of the entire group of cases will be our aim, together with the problems and the solutions incident to handling them. Typical cases in some of the main groups should be of interest in bringing out cardinal points and in showing the actual end results we would like to attain.

It is true that surgery in connection with the treatment of the injured hand is difficult and many times, after long hours of labor, the results are disappointing. That is no reason to assume an attitude of dislike or discouragement, however, or to pass off all hand cases as though they were something to be accepted and for which little could be done except in only a very few selected cases. The satisfaction and the gratitude which the patients show when we do obtain the desired results should stimulate us sufficiently to overlook the cases whose end results are discouraging. I wonder whether any case was ever presented but that something could be done to better that condition, even if it were only some minor procedure which would satisfy the patient's desire and peace of mind even though it did not actually improve the physical condition of his hand appreciably.

The hand conditions as we see them in a general hospital here in the States are old, of course, and most of them are healed wounds. They have been treated at other stations along the line and have been sent back for definitive treatment. In our discussion, we are referring, in the main, to this type of hand and its rehabilitation.

One could classify the cases of injuries to the hand which come under our supervision and treatment, in a general way, by grouping them according to the predominant type of injury. Of course, in a classification of this kind there is always some overlapping since many cases present a combination of injuries and might fall into more than one group, but for the purpose of this discussion we make the following classification: (1) burns; (2) contractures of all varieties; (3) traumatic amputations of the digits; (4) lacerated tendons; (5) post-infectious deformities; and (6) multiple injuries, involving ten-

dons, nerves and bones. Problems of the purely neurosurgical and purely orthopedic types are not treated by the Plastic Surgery Division and are, therefore, not included in these cases.

Burns. This type of injury includes burns caused by all agents and chemicals which are capable of producing burns, as well as by electrical energy which produces a deep burn and involves all structures in its path as well as the skin. In the average third degree surface burn a dense cicatrix forms in healing which is thick, tough and unyielding and prevents normal function of the joints even in cases in which no apparent joint injury is involved. Most of our cases of burns of the hands were on the dorsum of the hands and fingers, but in several cases the palms, also, were burned with burn contractures resulting.

In deep burns of the hands there is an involvement of the tendons and joint capsules as well as the skin, and with subsequent contracture, this produces the typical burn contracture deformities of the hands with hyperextension of the metacarpophalangeal joints, flexion of the first interphalangeal joint, and, usually, hyperextension of the distal joints of the fingers. Contractures develop across the web spaces and prevent abduction and adduction of the fingers and thumb. Thus, the hand is bound in a rigid covering which, in time, becomes more contracted allowing less use of the joints. Certainly, it is desirable to treat these cases as early as possible after their initial injury and to supply a good skin covering at the earliest moment rather than to allow them to granulate and to develop extensive contractures or to allow healed scarred epithelium which is tense and thin to become excoriated with secondary ulceration.

Contractures of All Varieties. In this group we include all contractures of the hand due to various etiology: lacerations, penetrating objects, shrapnel and bullet wounds, in which soft tissue is the primary tissue injured and in which heavy scar develops with healing. The contracture may be superficial and involve only the skin and subcutaneous tissue of the hand, or it may extend deeper and involve all the soft structures underlying it, including tendons. With healing, in these cases, contractures develop and produce deformities of either the flexion or extension variety, depending upon their site. Only one finger may be involved, or, if the contracture is extensive, several may be affected. Conservative treatment, including physiotherapy, seems to improve these conditions for a time, but usually the condition is not relieved permanently and surgery is ultimately required.

Traumatic Amputation of the Digits. Many of these patients, fortunately, have only one or two digits or merely parts of digits traumatically amputated, and a useful hand can be obtained with the remaining digits if the amputation stumps are covered satisfactorily. Usually the skin over the stumps is thin and atrophic or painful neuromas are present which prevent even light pressure on these areas. Frequently, because of pain, a patient will not use the other remaining functioning digits of his hand with resulting joint stiffness which further increases his disability. Surgery will relieve these conditions and even apparent lengthening of a short deformed digit can be obtained by deepening the adjacent web spaces.

Lacerated Tendons. We see a number of injuries produced by sharp penetrating objects which have healed more or less per primam but in which the original injury has divided the tendons, either flexors or extensors. In wounds in the field it is impractical to do primary tendon repair, and, frequently, because the wounds are dirty, it is inadvisable to repair them later at the station hospital even should the patient arrive within twelve hours, the so-called relatively safe period for primary tendon repair. This gives the patient an annoying condition of inability to use his finger or fingers which constantly get in his way in the ordinary

use of his hand. The condition, however, is very amenable to treatment and the patient can have function restored with usually satisfactory results by the surgical procedure of secondary tendon repair with tendon graft. A technic of tendon grafting is described herein.

Post-infectious Deformities. All wounds of the hand, if left open, are contaminated but fortunately most of them heal without apparent extensive infection. There is a group of cases in which virulent infectious processes develop with destruction of tissue and resultant deformities, many of which are contracture deformities of a general nature. Usually many incisions must be made in the course of the original treatment at the time of the acute infection in order to establish drainage. The infectious process destroys the smooth gliding action of the tendons if these sheaths are invaded and adherent useless tendons result. Joint destruction, also, is a frequent complication. Thus a digit or, perhaps, all the digits cease to function; general nutrition is disturbed; and the entire hand becomes painful and useless as far as function is concerned.

Multiple Injuries Involving Tendons, Nerves and Bones. There is a large group of combat injuries in which the injury is extensive and all the various tissues are involved to a greater or lesser extent. These cases are combination problems of the neurosurgeons, orthopedists and plastic surgeons and the problem is one of restoring all remaining structures to as near a functioning status as possible. Extensive surface scarring is usually present and the circulation is impaired. It is necessary to replace the surface covering with a pedicle graft after the scar has been excised. This improves the general condition of the hand. The orthopedic and neurosurgical problems should be corrected before the final tendon reconstruction is undertaken.

In evaluating the extent of damage of an injured hand, a history of the condition together with the previous treatment is essential. This takes time and patience on the part of both surgeon and patient, and frequently a hasty diagnosis as to the condition becomes disappointing to both surgeon and patient alike when the end results are tabulated. Immobilization of a part over a period of time produces atrophy and functional disability which sometimes makes the present picture appear more extensive than is actually the case. It is of paramount importance to make a very careful examination of the entire extremity as well as the injured hand. Local signs may have remote causes. The general condition of the hand should be observed, including the circulation, general state of nutrition and the atrophic changes. The general picture should then be outlined. Each part of the hand is checked separately for motion, pain and sensory disturbance. *X*-ray examination is imperative to check bone changes and deformities. The disability is noted and studied, and the anatomical basis for it worked out. This is important from the standpoint of diagnosis and evaluation and, also, from that of its correction. When one is able to visualize the pathological condition, one is able to outline the procedure to be followed in the rehabilitation of the hand and to give a prognosis. Certainly, one is not justified in subjecting a patient to the ordeal of an operative procedure which is long and laborious and will offer him only little possibility of improvement. By reviewing the condition carefully, the surgeon is able to avoid this in most cases. If the hand is nothing more than a non-functioning mass of painful scarred tissue resulting from wounds and subsequent infection, one would be performing a surgical feat rather than a sound surgical procedure to even attempt to rehabilitate it. Perhaps, amputation with prosthesis would be the solution.

Preoperative Treatment. After elective operative procedure is decided upon, certain preoperative care is necessary. The original injury must be well healed. No induration or reaction of tissue to healing

A

B

FIG. 1. A and B, preoperative photographs showing heavy dense burn scarring approximately five months after injury.

should be present. In the case of a tendon injury, three to six months should elapse before secondary repair. When the initial wound heals per primam, it is sometimes advisable to go into the hand within two months so that the divided tendons may be brought together, but in most of the severe hand injuries there will still be induration of tissues and stiffness of joints.

This is best taken care of by physiotherapy. Good joint motion is essential and until tendons can be repaired for active joint motion, passive motion with physiotherapy must be carried out. Physiotherapy also improves the circulation which, in turn, increases the nutrition of the hand so that induration disappears and scar tissue softens. In cases in which heavy scarring is binding and acts as a constriction—a condition which interferes with nutrition—a preliminary operation is necessary in which the scar tissue should be removed and good tissue covering supplied in the form of a pedicle graft. Our aim is to restore function and good

sensation and, certainly, these cannot be restored ultimately without first improving the nutrition of the hand. Frequently, joints are painful and, perhaps, temporary splinting will be necessary before physiotherapy is begun. This will quiet the joints which otherwise might be aggravated if physiotherapy were applied to them.

The patients are encouraged to take occupational therapy also as an adjunct to physiotherapy. In this way they do manipulations which are fairly complicated but they do them while interested in the projects on which they are working, which minimizes the constant reminders to move the joints. Thus, joint movements and active muscle exercises are carried out effectively and without conscious effort. This preoperative treatment prepares the patient for surgery and enables the surgeon to make a better evaluation and prognosis of the case.

OPERATIVE TREATMENT

Hand surgery is always difficult even when optimum operative conditions are available. Good lighting and suitable draping material, of course, are necessary. The hand should have a so-called "sterile" preparation which consists of shaving, soap and water scrubbing with trimming and manicure of the finger nails, and should then be washed in alcohol and wrapped in sterile towels the afternoon before the operation. The operative field is prepared using routine skin antiseptics.

General anesthesia is our anesthetic of choice, and most of our operative procedures are performed under sodium pentothal anesthesia.

It is essential to use a tourniquet during the dissection stage of the surgery in order to provide a bloodless field in which to work and not to damage important structures as well as to aid in making a clean anatomical dissection. An ordinary blood pressure cuff is used over a band of cotton, care being taken to apply the tourniquet snugly and smoothly. The blood pressure cuff is supported with gauze bandage and an Esmarch tourniquet is used to express the blood in the hand and forearm before inflating the cuff. While the Esmarch tourniquet is in place, the blood pressure tourniquet is inflated to between 240 to 260, and, after clamping the tube to secure the pressure, the Esmarch tourniquet is removed and the operation is started.

Incisions are made in the hand and on the digits along the flexion creases and not over points of pressure. Mid-lateral incisions are made along the digits. Good exposure should be obtained without unnecessarily long incisions. It is extremely important to be gentle in retracting skin flaps and in handling normal structures in order not to traumatize the tissue, thus minimizing the formation of postoperative scarring. All scar tissue should be removed if subsequent tendon work is to be done, or if it is to be done at the same procedure. Meticulous care in handling uninvolved tendons should be exercised to prevent scarring or damage to their gliding mechanism.

These are all small points, and yet a great difference is noted in postoperative results for their observance. The technic of tendon grafting and suturing employed is included in this article in a case report.

After exploration and exposure of the pathological condition, the procedure is decided upon. If it is found that bone or joint conditions are involved, that work should be corrected first either by the orthopedist or by the surgeon if he is equipped to handle the situation. At a later stage the nerve and tendon repair can be done in that respective order.

If extensive scar tissue is present and the skin is adherent to underlying structures, a pedicle graft is used to cover the defect after excision of the scar. The pedicle graft is usually turned up from the abdomen in cases in which the palm of the hand is involved and turned down from the abdomen in cases in which the dorsum of the hand is involved. This provides a good covering and subcutaneous

A

B

FIG. 2. A and B, final postoperative photographs taken approximately two months after last skin grafting procedure.

fat under which tendons can glide and also healthy tissue to replace the scar, thereby improving the general nutrition of the hand. Subsequent operations for nerve work or tendon grafting can then be approached through healthy tissue.

After the dissection is complete, the tourniquet can be released and the bleeding points ligated. Frequently, during the dissection, vessels which are cut can be ligated at the time, thus avoiding unnecessary bleeding. After hemostasis is secured, tendon grafting or whatever procedure is contemplated can be done. If it is desirable to do this work under the tourniquet, it can be reapplied in the same manner as previously described. It is well to remember that after release of the tourniquet pressure should be maintained on the wound with moist sponges

FIG. 3.

FIG. 4.

FIG. 3. Preoperative photograph showing contracture deformity.
FIG. 4. Attachment of abdominal pedicle to hand.

for five minutes because of the initial hyperemia. This saves unnecessary clamping of oozing points and then only active bleeders need be secured.

After the operation is completed, careful closure of the wound is necessary using subcuticular sutures and small suture material for skin closure with many closely spaced sutures. The suture material which we generally use is fine silk for ligatures and subcuticular sutures and fine silk for skin closure. A pressure dressing is always necessary in hand surgery to prevent undue oozing and hematoma from developing postoperatively. This can be accomplished by applying fine meshed gauze to the surface of the wound and fluffed gauze which can be compressed with gauze bandage. If fixation of the part is necessary, a molded plaster or metal splint can be applied. The dressing need not be excessively bulky so as to lose the effectiveness of the splint.

The operative procedure for excision of burn cicatrix of the hands and skin grafting is done under the same conditions as any other hand surgery. A tourniquet is used when scar tissue is dissected away. The scar tissue is excised completely down to a good base, care being taken not to expose the tendons but allowing the peritendonous tissue to remain so that the gliding motion of the tendon is preserved and its function is not disturbed. Usually the burn does not involve the tendon except in cases of very deep burns or electrical burns. The grafting procedure and the dressing are included in detail in a case report.

POSTOPERATIVE TREATMENT

Elevation of the limb postoperatively for any surgery done on the hand is essential in order to minimize postoperative discomfort and swelling. Inspection of the wound can be done about seven to

FIG. 5.

FIG. 6.

FIG. 5. Pedicle after revision.
FIG. 6. Double exposure photograph four months postoperatively showing range of motion.

ten days postoperatively by opening the bandages without disturbing the hand and forearm from its splint. Sutures can be removed at this time and the dressing folded together again and rebandaged. Elevation of temperature, pain and throbbing sensation in the hand, of course, call for inspection of the hand at any time. The primary dressing after grafting can be done on the sixth to the tenth day at which time the sutures and skin overlap can be removed.

In the case of tendon work, fixation of the hand in plaster for three weeks without motion is maintained and support is then given by elastic bands. Then physiotherapy can be started. The patient is encouraged to move his hand actively immediately after its removal from the cast with elastic traction used as a safeguard against sudden pull on the healing structures. In skin grafting procedures for burns under the usual conditions of "take," motion can be started within two weeks.

Physiotherapy for periods of months is essential postoperatively before final results can be evaluated. Improvement can be expected for six to twelve months or perhaps even longer. Occupational therapy to engage the patient in intricate manipulative work and hand exercises are all very essential. Good physiotherapy treatments with the patient's full cooperation are essential for good results.

CASE REPORTS

CASE 1. *A Typical Burn Case of Hand Injury:* This case involving the entire dorsum

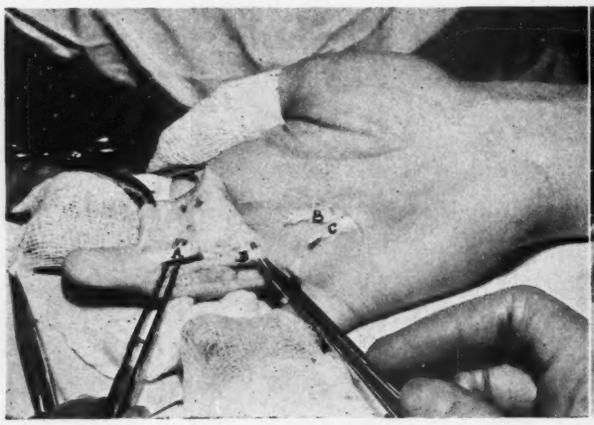

FIG. 7. Showing the ends of the flexor tendons exposed. A, distal end of the flexor digitorum profundus; B, proximal end of the flexor digitorum profundus; C, proximal end of the flexor digitorum sublimis; D, digital nerve and vessels.

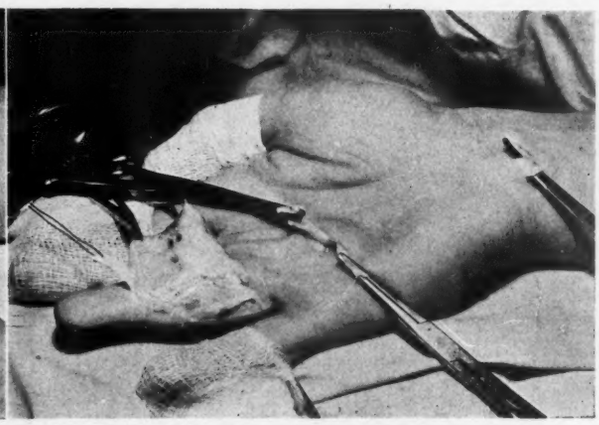

FIG. 8. View showing incision made in the wrist. Involved flexor digitorum sublimis tendon isolated under clamp.

of both hands and fingers is a typical burn case. The patient sustained third degree burns of both hands in a gasoline explosion aboard ship. The granulating areas were allowed to epithelialize and on admission to this station all areas were healed. Heavy burn contractures were present over the dorsal surfaces of the hands and fingers preventing full flexion of the metacarpophalangeal and interphalangeal joints of the fingers and thumb. (Figs. 1 and 2.) Grafting of the right hand was done five months after the burn; each hand was done at a separate operation. The entire scar tissue was dissected away using a tourniquet and sodium pentothal anesthesia, care being taken not to remove the peritendonous tissue. Incisions were made in the web spaces to deepen them. The tourniquet was released and hemostasis secured with No. 0000 white deknatel silk, and the tourniquet re-applied while the skin graft was sutured into position. Split thickness skin grafts of .018 inch thickness cut with a Padgett dermatome were used to cover the denuded surface. Darts were cut in the graft over the web spaces and sutured into place in the denuded areas between the fingers. Suture material used was No. 0000 black deknatel silk. Approximately one and three-fourths dermatome drums of skin were used for the right hand and approximately one drum of skin for the left. Unless the webs are deepened and grafted, contractures will develop across them. In spite of this procedure, minor corrections of the web are often necessary, as was true in this case. A pressure dressing was applied consisting of a single layer of xeroform gauze over which were

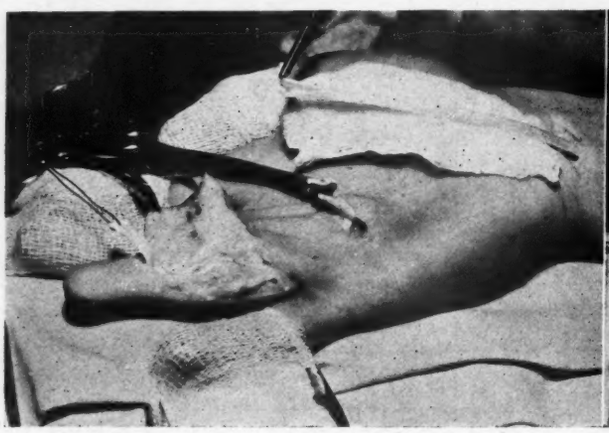

FIG. 9. The flexor digitorum sublimis tendon has been pulled through and is to be used as tendon graft to establish continuity between divided ends of the profundus. It is divided at the wrist and proximal end allowed to retract.

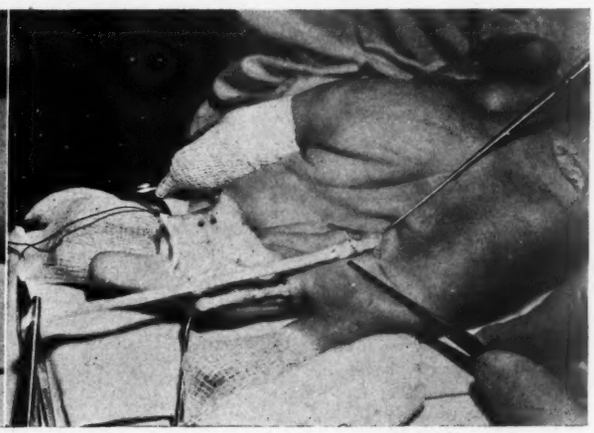

FIG. 10. Proximal suture of tendon graft complete.

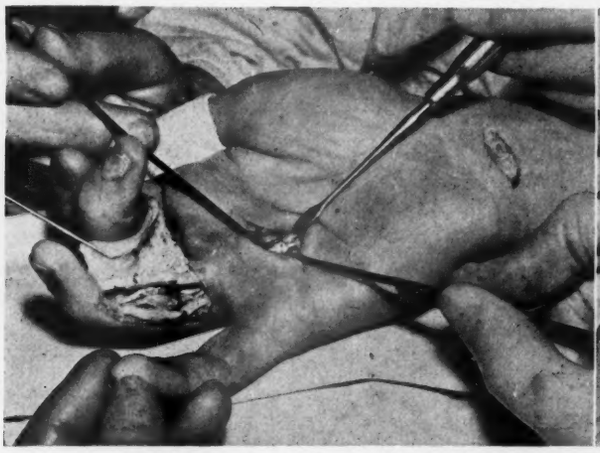

Fig. 11. Distal suture line of tendon graft completed.

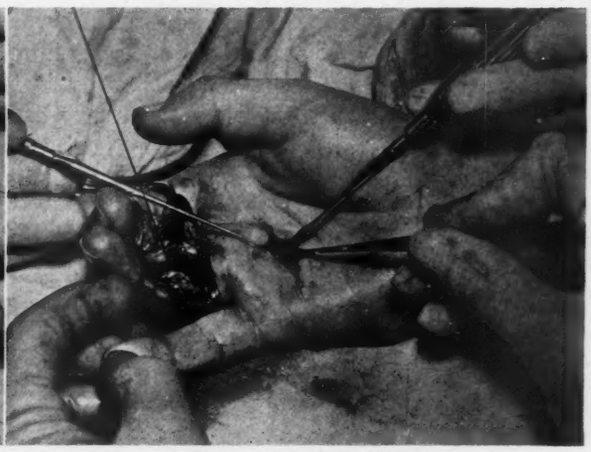

Fig. 12. A thin, veil-like piece of tissue from the fascia lata of the thigh has been secured and wrapped around the tendon graft in its entire extent as well as beyond the suture lines. It is fixed in position using fine silk sutures.

placed moistened saline sponges and machinist's waste secured with gauze bandage with the hand and fingers in a flexed position. After the dressing was completed, the tourniquet was released. In using the tourniquet the graft site is bloodless; hematomas do not form under the graft while it is being sutured in place or before the pressure dressing is applied.

The "take" of the grafts was practically complete. The primary dressing was done on the sixth postoperative day, at which time all sutures and overlaps of skin graft were removed. Daily dressings using light pressure were done thereafter. Physiotherapy treatments were started about the fifteenth postoperative day.

The same operative technic was employed on both hands, with the left one being grafted about one month later. A minor grafting procedure was done to the web spaces between the thumb and index finger of the right hand and between the fingers of the left hand about two months later.

A good covering replaced the heavy burn scar and full function of the hands was restored.

Case II. *Contracture Deformity of the Hand:* This case demonstrates a contracture deformity which was deep and involved the flexor tendons. While the case is relatively simple, involving the flexor tendons to one finger, it includes the principles of repair which might apply if the entire hand were involved in the same condition. The patient received lacerations of his hand across the distal palm on its ulnar side and proximal portion of his little finger with division of the flexor tendons near the base of the finger. Primary tendon repair and digital nerve suture were done and, with healing, scar tissue formed and contracture resulted with flexor deformity of the little finger. The finger was carried in about 50 per cent flexion. There was no active flexion action present in the interphalangeal joints.

The first plastic procedures were done one year after injury under sodium pentothal anesthesia and using a tourniquet. All scar tissue in the finger and the distal palm was removed as well as the scarred part of the flexor tendons, leaving the proximal ends of the flexor tendons free in the palm and the distal end of the unscarred flexor digitorum profundus tendon free in the finger. The insertion and the adjacent proximal inch of the flexor digitorum sublimis tendon was removed since it was involved in the scar tissue. An abdominal pedicle

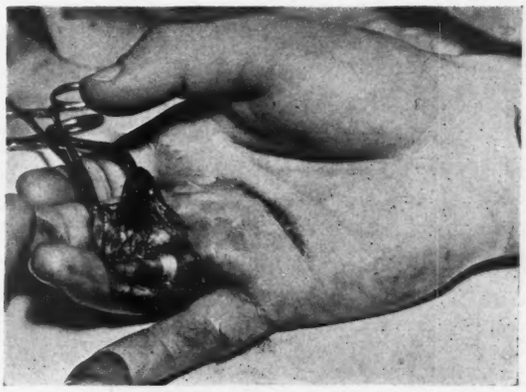

Fig. 13. Repair completed; reconstructed restraining ligament shown.

was used to cover the defect. The pedicle was divided fifteen days postoperatively and a final revision done later. Active physiotherapy was started fifteen days after the pedicle was revised to keep the joints in active condition.

Four months later a tendon graft was done to establish continuity of the flexor digitorum profundus tendon to this finger. The distal portion of the flexor digitorum profundus tendon was exposed by an incision along the lateral attachment of the pedicle graft on the little finger. The proximal ends of the flexor tendons of this finger were exposed through an incision in the distal flexion crease of the palm and the tendon graft was done using the flexor digitorum sublimis tendon.

The tendon graft was sutured using the Bunnell method of tendon suture with fine silk. The wounds were closed using fine silk as subcutaneous sutures and closely spaced interrupted sutures of fine black silk for skin approximation. A pressure dressing using fluffed gauze was applied and the hand was fixed in a plaster splint with flexion of the wrist and normal flexion of the fingers for three weeks postoperatively. The wounds were inspected by unfolding the dressing on the tenth postoperative day when the sutures were removed. The dressing was again secured.

When the cast was removed the patient was allowed to move his finger as much as he was able with active motion. A light elastic band connected with a thread through the finger nail and attached to the wrist protected the finger from too forcible extension. This remained in place for one week and was applied only at night for one more week. Physiotherapy was started the fifth postoperative week. Four months later the function had been restored to about 75 per cent of the normal range. (Figs. 3 to 6.)

The following series of photographs show the technic of tendon grafting used. It will be noted that this series of photographs are not those of the actual procedure done in the case report but demonstrate a similar condition of tendon grafting where the ring finger was involved. (Figs. 7 to 13.)

COMMENTS

Rehabilitation of the injured hand is in most instances probably one of the most difficult tasks which the surgeon is called upon to perform. By careful examination and planning, together, with meticulous surgery, this work can be accomplished with satisfactory results in many cases. Good cooperation on the part of the patient in taking active hand exercises and following physiotherapy treatments is most essential for good results.

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BONE SURGERY OF THE HAND

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THE severely mutilated hands caused by the havoc of war have left many types of residual deformities and disabilities to be dealt with. In civilian practice these were comparatively rare. On the Orthopedic Service at the Valley Forge General Hospital many such hands were encountered.

A B

FIG. 1. A, loss of thumb and first two fingers; B, transfer of third metacarpal onto greater multangulum.

Bone surgery of the hand is the restricted title of this paper because inclusion of the associated surgery of the skin, tendons, muscles and nerves would be far too comprehensive and may be dealt with separately. It should be clearly understood, however, that in nearly all of these cases bone surgery played only a part, and sometimes but a small part, in the rehabilitation of the hand.

Before any surgery was begun on the hand a most careful evaluation of its prospective function was made. For instance, a finger without sensation was a pretty useless prospect unless the nerves could be restored. So also was a finger without tendon action. Bone surgery itself was not indicated unless it would restore added usefulness to the hand, and it had to be considered always in relation to the whole.

A

B

FIG. 2. A, shrapnel riddled scar full of scar tissue; B, bone block between first and second metacarpals to hold thumb in opposition.

Needless to say surgery of the bones could not be performed on the hand through scar tissue. Good skin with subcutaneous tissue was a necessary prerequisite for this work. In deep hand wounds, such as are illustrated here, nearly always a full thickness skin graft was needed. This was done by the plastic service beforehand, either by local or

A B

FIG. 3. A, loss of three fingers plus mal-union of phalanx of index finger and loss of opponens power in thumb; B, rotation osteotomy of first metacarpal to aid opponens action and correction of alignment of phalanx by osteotomy.

A B

FIG. 4. A, dislocation of first metacarpal; B, reduction.

remote flap methods. After this was accomplished it was important to decide upon the next surgical procedure. Usually the bone work came after the skin grafting because it formed the basic structure upon which to build the action of the fingers. Occasionally, nerve grafts or neurolysis were performed earlier or at the same time as the bone work. Tenolysis, tenorrhaphy or tendon grafting were sometimes also performed with the bone surgery. Between each such procedure a considerable interval of active use was given to restore the function of the hand as far as each intermediate step would permit.

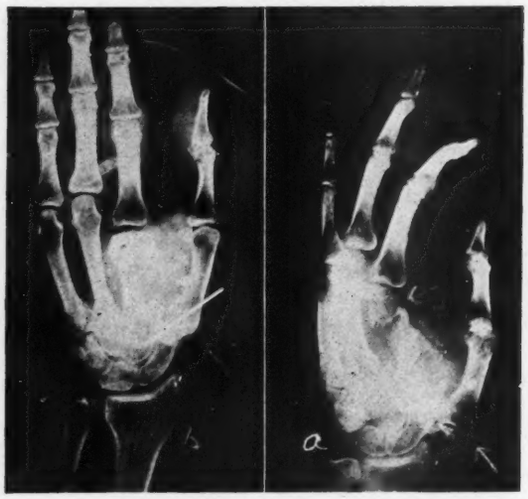
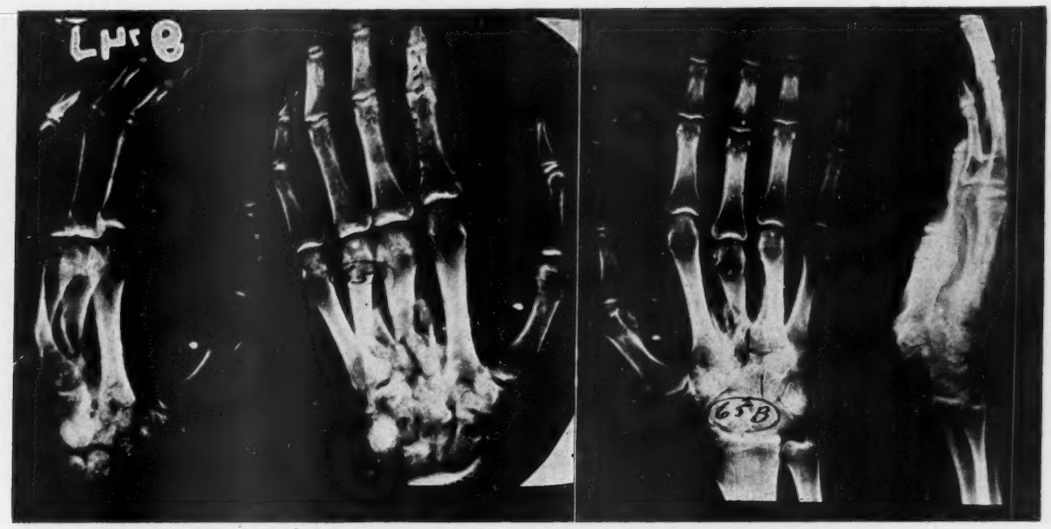


FIG. 5. *a*, dislocation of first metacarpal and part of greater multangulum and also 90-degree angulation of third metacarpal fracture; *b*, reduction of first metacarpal with excision of blocking remnants of second metacarpal; malalignment of third corrected later.

THUMB

Loss of a thumb could sometimes be partially compensated for. If just the two phalanges were gone, the web between the first and second metacarpals was deepened, and a fair grasping and holding digit was shaped out of the first metacarpal and the thenar tissues. Three or four successful cases of this type confirmed the usefulness of this plastic procedure.

However, when the first metacarpal was also gone, a far more serious handicap resulted because a hand without a thumb is quite useless. Therefore, some type of thumb reconstruction was worth while. Case 1 illustrates how such a problem was met. Fortunately in this patient, a large amount of soft tissue had been preserved and the second metacarpal was available for a bone graft because the index finger had also been amputated. This useless metacarpal was transferred over to the thenar side and set into the greater multangulum. In the event that this metacarpal had not been available a tibial graft could have been used.



A B

FIG. 6. A, dorsal angulation of metacarpal fractures; B, correction with improved flexion at metacarpophalangeal joints.

A B

FIG. 7. A, loss of fourth and fifth fingers with mal-union of the second and third metacarpals; B, corrected alignment of metacarpals.

The loss of the opposition action of the thumb in Case II, was caused by the destruction of the thenar muscles and a dense scar contracture. This was overcome by freeing the scar and bringing the thumb around into an opponens position. To hold it there a small bone block was taken from the tibia, was wedged down between the first and second metacarpals and held in place by a Kirschner wire. A similar problem was met in Case III, when opposition of the thumb was also lost because of scar tissue contracture. In this instance the thumb and remaining finger possessed fair flexor and extensor power and after freeing the scar an osteotomy was performed at the base of the first metacarpal and the shaft rotated.

A B

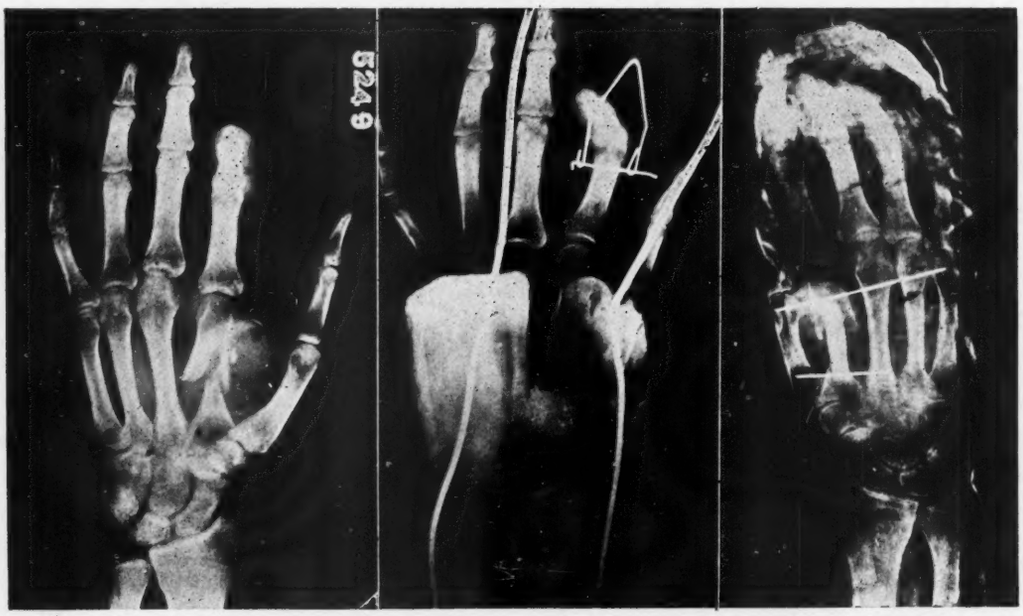
FIG. 8. A, non-union of fourth metacarpal; B, dual bone grafts.

This permitted it to move into a position of opposition to the index finger when later a tendon transplant was done to motivate it.

Dislocations of the base of the first metacarpal were not uncommon. Obviously a thumb could not function when the first metacarpal had slipped up into the wrist as in Cases IV and V. The reductions were not easy but they were held in place by Kirschner wires and fortunately they did not tend to recur when the wires were removed in five or six weeks.

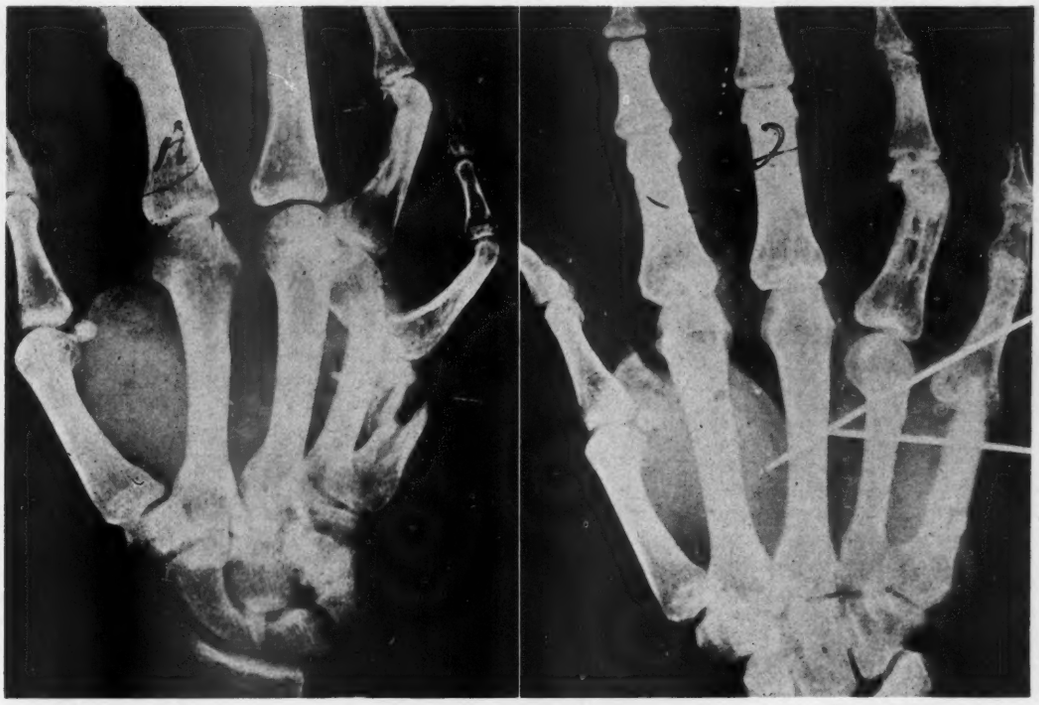
METACARPALS

Malunion of metacarpal fractures could be a real problem. Case VI was an example of the severe handicap which often followed the dorsal angulation of the metacarpals.



A B C

FIG. 9. A, non-union of second metacarpal; B, skeletal traction to restore length of finger; C, tibial bone graft notched distally to match shaft and doweled proximally into base.



A B

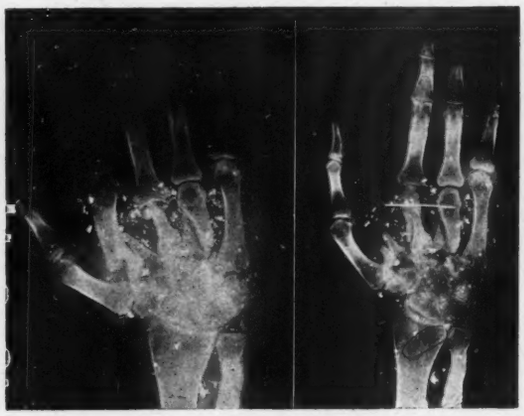
Fig. 10. A, non-union of fifth metacarpal and mal-union of proximal phalanx of fourth finger; B, tibial bone graft notched into proximal shaft and doweled into phalanx, sacrificing the joint; corrective osteotomy on phalanx performed later with flexor tendon graft.

In such a position the heads of the metacarpals had dropped forward and the whole intrinsic muscle mechanism of the fingers was thrown out of gear. This resulted in severe extension contractures of the metacarpophalangeal joints which were intractable, despite forced use and many types of traction apparatus. True lateral *x*-ray views were helpful to illustrate this deformity and the correction of this malalignment was well worth while, although the final result was tempered by whatever residual deficiency existed in the intrinsic mechanism. It was often necessary at operation to do a capsulectomy on the collateral ligaments of these joints in order to obtain 90 degrees of flexion and also to run Kirschner wires through the heads of several metacarpals to hold them up in place until healing occurred. Further it was found advisable postoperatively to maintain the metacarpophalangeal joints in a position of 90 degrees flexion for two or three weeks in order to prevent the recurrence of these extension contractures. At the same time active use of the phalangeal joints was encouraged to prevent stiffness of the fingers.

Lateral angulation of the metacarpals also left a deformity which had to be corrected. Case VIII shows a terribly mutilated hand with complete loss of the fourth and fifth fingers along with their metacarpals. The second and third metacarpals were grossly distorted but their alignment was corrected as shown in the illustration.

BONE GRAFTS

Non-union with loss of substance of the metacarpal was a common finding. A number of cases are presented to illustrate the different types of bone grafts which were used to fill in these defects. Case VIII shows one of our earlier types. Two small dual grafts were used in order to grip both open ends in a vise which was held by a screw. Further experience developed two simple and more satisfactory methods of matching the grafts with a fair degree of self fixation. When



A B

FIG. 11. A, useless remnant of index finger with loss of head of second metacarpal; apparent non-union of their metacarpal but at operation it was found to be firmly united; B, removal of second metacarpal and transplant of distal half of fifth metatarsal onto shaft of third metacarpal after restoration of joint space.

A B

FIG. 12. A, loss of fourth and fifth metacarpals and carpal bones leaving intact fingers with sensation and tendons; B, V-shaped bone graft.

the head or the base of the metacarpals was involved a hole was gauged into it and the end of the graft was doweled to fit and was then tapped in snugly. In fractures of the shaft of the metacarpal the donor and recipient ends were notched in opposite planes with a small rongeur so that they locked firmly when jammed together. One or two Kirschner wires were usually inserted transversely through normal and fractured bones to give added strength to the fixation.

The closer to the normal length the metacarpals could be restored, the better was the ultimate function of the hand. Therefore, if there was any hope of stretching out the distal end, preliminary skeletal traction was used as in Case IX. A partial restoration of length was accomplished and then a graft was inserted. Case X also illustrates an earlier experience with a bone graft from the tibia to replace the loss of the distal half of a metacarpal. In this instance the joint was sacrificed in order to provide bony support to the finger.

Such a disadvantage from sacrificing a metacarpal-phalangeal joint of an important finger led us to the experiment of Case XI. This officer had been completely blinded, and his finger function was truly important. The index finger was already missing so that its metacarpal stump was removed to eliminate scar and to make a smooth cleft between the thumb and middle finger. The space formerly occupied by the head of the third metacarpal was filled with dense scar tissue which had to be meticulously dissected out and a soft tissue covering prepared. The distal half of this fifth metatarsal was then borrowed for the graft and was notched into the proximal end of the metacarpal and fixed with a Kirschner wire. It seemed worth while to try this procedure because previous experience had shown such uniform success in metacarpal grafts. This single contact graft grew perfectly and the joint moved well. The flexor tendon had remained intact. Later after union of the graft and motion in the joint had been well established, an extensor tendon graft was added and the finger functioned very well.

The problem of complete loss of the fourth and fifth metacarpals as well as some of the carpal bones was met in Case XII. Here the index and middle fingers were badly damaged by scarring and stiff joints. Ironically, the fourth and fifth fingers were left in good condition with intact tendons and nerves despite the missing metacarpals. A V-shaped bone graft was inserted to support these fingers.

A B C

FIG. 13. A, palmar scar; B, loss of half of fourth metacarpal plus loss of sensation and tendons in finger; C, elimination of fourth finger with its metacarpal shaft and transfer of fifth metacarpal onto base of fourth.

A B

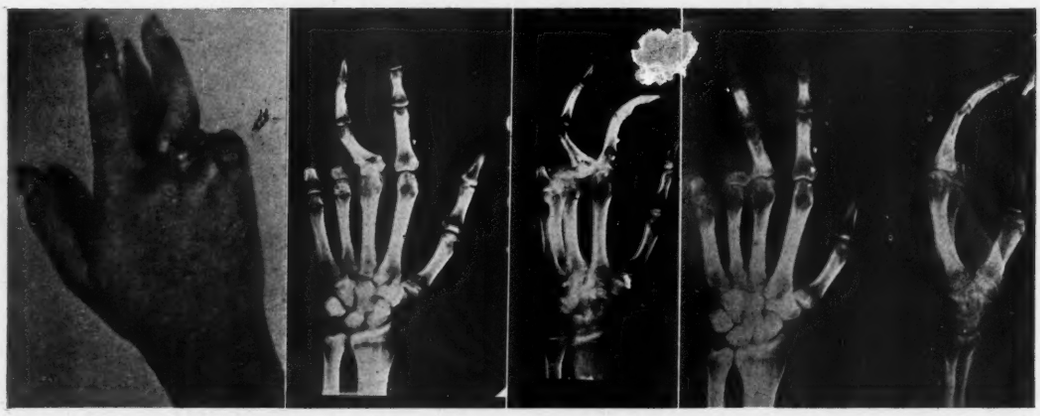
FIG. 14. A, loss of fourth finger with deformity of third metacarpophalangeal joint surfaces; B, excision of shaft of fourth metacarpal and transplant shaft of fifth onto its base; arthroplasty of third metacarpophalangeal joint.

TRANSFER OF METACARPALS

Many times the loss of one finger has had an adverse effect on the intrinsic muscle mechanism of the adjoining digits. Scar contractures intervened and ofttimes the abnormal flexor pull angulated the finger. To counteract this effect it seemed wise several times to "close" the hand by shifting the metacarpals. Cases XIII and XIV show two instances in which the fifth metacarpal has been shifted over on to the base of the fourth. The problem in Case XIII can readily be appreciated. The distal end of the fourth metacarpal was missing and the finger was without nerve and tendon supply. So it was sacri-

A B C

FIG. 15. A, front of split hand; B, dorsum—third metacarpal missing; C, transfer of second metacarpal onto base of third to close split.



A B C

FIG. 16. A, mutilated hand with bad scarring which had to be excised; B, deformity of proximal phalanx of middle finger; C, correction by osteotomy.

ficed and the fifth finger was moved over to take its place by shifting that metatarsal over on to the base of the fourth. Enough skin and soft tissue were thus made available to excise the palmar and dorsal scars.

Case XIV was similar except that the ring finger was already missing. The fourth metacarpal was removed and the fifth was shifted over on to the fourth base.

On the other side of the hand in Case XV, the second metacarpal was shifted over onto the base of the third in order to close a cleft hand. The result in all of these transfers depended upon the quality of the remaining intrinsic muscles and varied inversely with the amount of scar tissue present. In general this operation was found to be a definitely helpful procedure for the proper indications.

ARTHROPLASTY

Numerous arthroplasties of the metacarpophalangeal joints were done and one is shown in Case XVI which also had the transfer of the metacarpal. The base of the first phalanx was trimmed up neatly and the sleeve mechanism around it adjusted. In other cases the deformed heads of the metacarpals were reshaped. The results in both these types of arthroplasties of the metacarpophalangeal joints were quite good. Plastic cups were tried but were found to be unnecessary in so far as preventing adhesions, and to have the active disadvantage of slipping around. The most important factor was discovered to be the preservation of an even balance in the intrinsic muscles and freedom of the

sleeve mechanism so that the finger did not tend to angulate to one side when flexed.

The successful graft of the metatarsal head with its intact cartilaginous surface into the metacarpophalangeal joint in Case XI, led to the surmise that this procedure could be carried along to further usefulness in restoring damaged metacarpophalangeal joints. Arthroplasties of the phalanges were not successful as a rule because they left unstable joints. Whenever necessary, such damaged joints were fused, especially in the little finger, at the optimum position of 45 degrees of flexion.

OSTEOTOMIES

A rotation osteotomy of the first metacarpal to bring the thumb into opposition was shown in Case III. A second glance at this case will show that a rotation osteotomy was also done on the first phalanx of the index finger to correct angulation. Case V had an unusual mal-union of 90 degrees of the metacarpal shaft fracture which had to be corrected to improve the function of the metacarpophalangeal joint. In Case X a successful osteotomy of the proximal phalanx of the fourth finger was performed in order to prevent the finger from flexing away out of line, and at the same time a flexor tendon graft was implanted successfully. Case XVI likewise shows clearly the advantage of an osteotomy for a deformed phalanx. The scar was excised, the mal-union broken up and this finger straightened out very well. The method of fixation after these osteotomies was usually to insert short ends of Kirschner wires either obliquely or longitudinally through the ends and leave them until union occurred.

FIG. 17. A, severe ischemic contracture of wrist and hand; B, tendon length obtained by carpectomy; functional position by fusion of hand to radius by sliding bone graft from radius into third and fourth metacarpals.

CARPECTOMY

An extreme condition of flexion contracture (Volkman's type) of the fingers and wrist followed a lesion of the brachial artery and radial nerve in Case XVII. Sufficient tendon length for fair finger action was obtained by a carpectomy. A sliding bone graft from the radius across to the third and fourth metacarpals fixed the hand in a functional position so that

the weak muscles could exert fair power on the fingers.

SUMMARY

Many deformities and handicaps of the hand require bone surgery of different types. Bone grafts have been used to form a first metacarpal, to make a bone block between the first and second metacarpals, and in many varied forms to make up loss of bone substance in metacarpals. A metatarsal head with its cartilaginous covering was successfully transplanted onto a metacarpal shaft to form a new metacarpophalangeal joint.

Mal-union of metacarpals often required correction by osteotomies to realign the metacarpal heads and restore the intrinsic muscle function. Rotation osteotomies were also useful to correct mal-union of both metacarpals and the phalanges.

Closing in of the hand by metacarpal shifts onto the bases of their vacant neighbors was discovered to be an advantageous procedure under proper indications.

Simple arthroplasties of the metacarpophalangeal joints were practical and reasonably successful.

CONCLUSION

A series of hand problems have been presented in which various types of bone surgery have accomplished an improvement of function in severely deranged hands. Practically no failures of union have been noted either after osteotomies or bone grafts.

REPAIR OF AVULSION WOUNDS OF THE HANDS AND FEET BY THE FLAP GRAFT TECHNIC

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THE treatment of avulsion wounds of the hands and feet in a general hospital functioning in the Mediterranean theatre of operations during World War II presented definite problems which necessitated a closure technic providing a thick fatty skin cover within the shortest period of time. All of these wounds were either penetrating or perforating; tendons, nerves and bones were exposed. In most cases the bones were fractured and often fragments were missing. While many of the cases were clinically clean immediately after débridement at evacuation hospitals, all were contaminated and many were infected by the time the general hospital was reached. Unless covered with a skin layer early, exposed tendons and bones soon became necrotic. To prevent further loss of the deep tissue structures, and to provide for the earliest functional results, all skin grafting technics were investigated.

The free grafts, Thiersch, split skin and full thickness could not take over the above mentioned deep structures. A fat containing pedicle type of graft was consequently indicated which would (1) cover exposed bone, tendon or deep irregular muscle defects, (2) not adhere to the underlying structures, and (3) not contract excessively.

Three such types of tissue covers were available; the contiguous skin flap, the tube and the flap grafts. The contiguous skin flap or the utilization of the tissue adjacent to the wound was limited because of the relative immobility and inelasticity of the tissues of the hands and feet due to the paucity of subcutaneous fat. This was especially true for large wounds.

The tube graft was an ideal technic for covering but required at least three, and more often, additional operations to cover a defect. To decrease the number of the operations required the flap graft was reinvestigated and used instead of the tube graft.

The flap graft repair was first described by the Indians who used the forehead as a donor site for the repair of facial wounds. Tagliacozzi in the sixteenth century, made use of the arm as a donor site for similar repairs. This general method of skin transfer remained the common form of grafting up to the beginning of this century when Filatov tubed flaps to allow transfer of large amounts of tissue, usually from the chest or abdomen, to distant parts of the body. Except for certain types of cases, the flap graft was gradually discarded for the tube graft.

TABLE 1
AVULSION WOUNDS OF THE HANDS AND FEET

	Flap Repairs	Combined Flap and Split Skin	Split Skin
Hands	34	0	15
Feet	12	3	14
		Total flap repairs 49	
		Total wounds 78	

As the name implies, the flap graft is simply a flap of skin, subcutaneous tissue and fat which is raised from a relatively non-functioning area and while maintaining its nourishment through an attached base, is sutured on three sides and its undersurface to the defect. When sufficient blood supply from the defect site has entered the skin graft, the flap is severed from the donor site and becomes part of the new location.

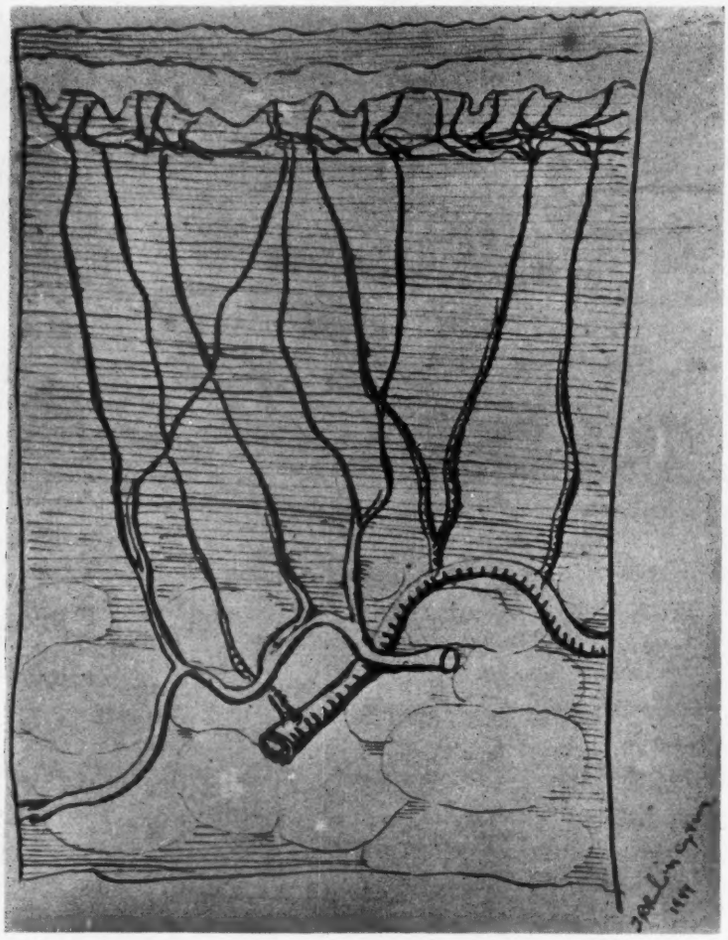


FIG. 1. Diagram of section through skin. Diagram illustrates the location of the large vessels in the fatty tissue. One can see how thinning the flap could easily cut the blood supply.

Wounds of the hands and feet presented defects which could be brought to the donor sites with relative ease obviating the necessity for tubing. An ideal situation was thus presented for the use of the flap graft.

TECHNICAL CONSIDERATIONS

Donor Sites for Hand Defects. The usual donor site was the abdomen. Practically all flaps were cut with the pedicle facing posteriorly or diagonally superiorly, so as to allow the lower thoracic and posterior lumbar vertebral vessels to enter the flap. On occasion when indicated, the flap base was directed superiorly or inferiorly with the source of blood supply coming from either the thoraco-epigastric vessels or the superficial iliacs coming up to anastomose with them. At no time were flaps cut across the midline since the vessels of the abdominal wall do not go beyond the linea alba. The flaps were thick and included all layers of skin and fat down to Scarpas fascia; this fascial layer was not included in the flap. All deep blood vessels were definitely included by this procedure. (Fig. 1.) The bulkiness of the graft was not considered at this time since the cosmetic factor was considered unimportant. The fat, if trimmed at all, was carefully cut so as to avoid vessels of any size. In some of our early cases, while attempting a cosmetic as well as a functional result, neglect of this important fact led to edge necrosis. The size of the flap varied considerably; we did not exceed the rule of "length no more than three times the width" but always tried to get the widest pedicle possible. The flaps cut were larger than the defect only because the pedicle of the flap had to bridge the gap

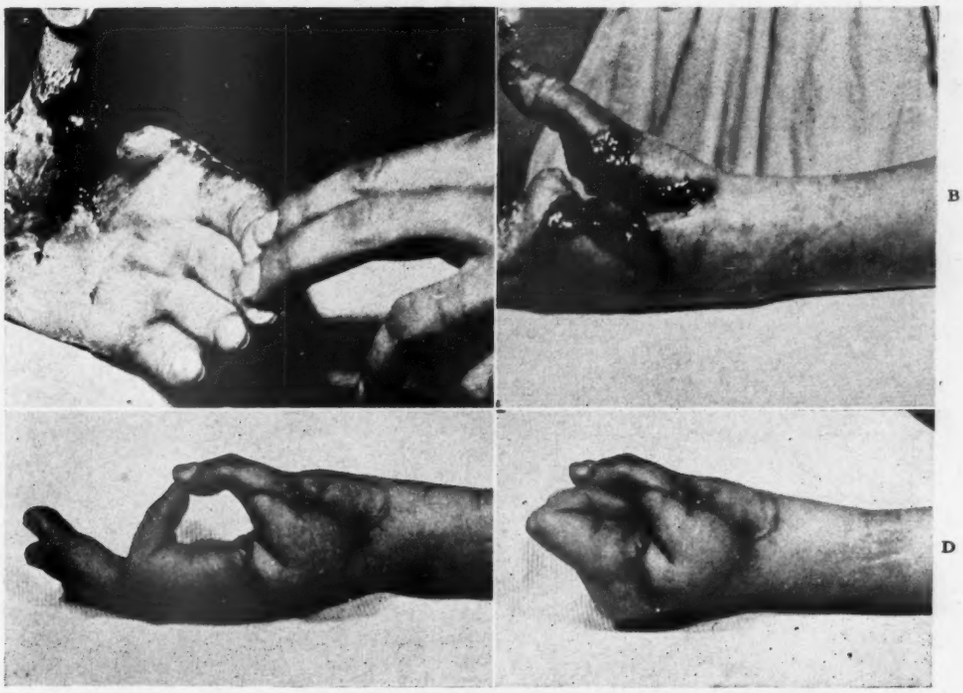


FIG. 2. Marked avulsion wound of the first web space, with comminuted fractures of the first phalanges and the first metarcarpal. Tendons, both extensors and flexors of the first and second fingers were exposed. There was a loss of part of the tendons of the first finger. Wounded by shrapnel, the wound was débrided the same day. The patient was admitted to General Hospital fifteen days later. On the twenty-third day, he was seen by the plastic service and accepted. On the twenty-fifth day a second débridement was done, necrotic tendon was trimmed and the wound was greatly decreased in size by undermining and sliding contiguous flaps. On the twenty-ninth day the hand was attached to an abdominal flap and severed from the abdomen on the forty-third day. On the sixty-third day a fusion of the first metacarpal phalangeal joint and the interphalangeal joint was done because of non-union. The hand healed rapidly thereafter and the patient was placed to B duty on the 103rd day. Illustrations show the resulting function. Had the patient been seen by the service sooner, many days in time would have been saved.

between the donor site and the defect. The graft size had to include, therefore, an easily mobile pedicle as well as the defect. A loose pedicle was important to avoid pull on the graft when the hand was placed on the abdomen. The part sutured to the defect was placed with normal skin tension, since we believed that an oversized graft would contract and compress the small vessels causing venous stasis. An undersized graft under tension would strangulate the entering blood supply and cause arterial avascularity and necrosis.

Donor Sites for Foot Defects. The anterior, lateral and medial aspects of the thigh were chosen as the best donor sites for the foot defects. In most cases the base of the flap was placed in the superior direction. However, in cases in which the defect was on the lateral aspect of the foot or ankle, a retrograde flap was raised, the blood supply coming from the rich plexus of vessels about the knee.

In search for a more comfortable donor site, the lower leg was considered but found unsuitable for several reasons. The subcutaneous tissue contained little fat, a limited blood supply, and lacked contour for large defects. Another disadvantage was the lack of silent areas on the leg. Any flap raised would uncover tendons or bones, which in turn would have to be covered by a fatty layer. Still another disadvantage was the disturbance of the sensory nerves when tissue was removed; this was not only annoying to the patient but might make him susceptible to further trauma. An additional disadvantage was the possibility

of vasomotor disturbances often associated with surgery of the legs. Some people have a high vascular tone and are sensitive to vasoconstrictor effects of cold, pain and trauma. The operation of lifting a flap and then placing the leg in a confining cast for any length of time can be followed by a serious increase of vascular constriction, so serious in some cases as to cause necrosis of tissue when least expected.

TABLE II
DISTRIBUTION OF HAND DEFECTS REPAIRED BY FLAPS

	No. Cases
1. Segments of fingers only	8
2. First web space	6
3. Dorsum only	7
4. Combined dorsal and volar flaps for perforation	2
5. Dorsal flap only for severe perforation	1
6. Defects post-amputation with exposures of bones and tendons.	
a) Longitudinal hand amputation of 1st metacarpal and thumb	2
b) Longitudinal amputation of 5th metacarpal and 5th finger	2
c) Longitudinal amputation of 4th and 5th metacarpals and 4th and 5th fingers	1
d) Horizontal amputations of Nos. 3, 4, 5 fingers, exposing heads of metacarpals.	1
e) Amputation and exposure 2nd metacarpal; loss of skin dorsal and volar surfaces	1
f) Same as above only 3rd metacarpal involved	1
g) Same as above only 4th metacarpal involved	1
h) Same as above only 5th metacarpal involved	1

When there was doubt in our minds as to the circulation of the flap, either because of the position or the size, we resorted to the delaying technic. The technic of delaying is merely the principle of a gradual rather than a sudden reduction in blood supply.

The ideal technic called for two delays. The primary consisted of two parallel lines along the side of the flap, cutting down to deep fascia and undermining along the entire size of the required flap. The second stage was the connection of these two lines. Lifting the whole flap on all sides but the base in one stage might cause necrosis at the distal end because of lowered blood supply. The cutting of the blood supply from its sides and from below forced dilation and engorgement of the blood vessels coming through the base pedicle. The vessel arrayed themselves longitudinally and enhanced the circulation for the eventual transfer. We usually waited seven days before the next stage.

All flaps raised were of a single pedicle type. A double pedicle would have sacrificed mobility of flap tissue, making it difficult to cover the extremity wounds; then, too, the early repair of the donor site would be hampered, since undermining and closure of the flap defect site when attached on two ends could be difficult. Lastly, since the extremity would have to be placed under a double pedicle flap, the flap itself would have to be cut much larger to accommodate the thickness of the extremity.

Recipient Site. Only frankly necrotic tendon and bone were surgically removed before a flap was placed over the defect; infected tendons were not débrided. If *x*-ray showed an osteomyelitic process in comminuted pieces of bone, the pieces were removed at a secondary débridement. All granulation and early scar tissue was removed, making sure there would be no barrier for new blood vessel penetration. Fresh skin edges were cut and then slightly undermined to facilitate suturing to the flap. Since many wounds were of the bursting as well as the lacerating type, the size of the defects could often be decreased by undermining the adjacent skin edges, sliding or rotating that tissue and then suturing. Not only did this decrease the size of the flap to be raised, but also gave a regular edge to the wound. In some of the large foot defects, it was thought advisable to decrease the size of the defect because of the difficulty in obtaining sufficient flap from the thigh. We combined a flap and split skin technic. Since the tissue of the foot does not lend itself to contiguous sliding or stretching, a heavy split skin graft (.024 of an inch) was taken by dermatome and

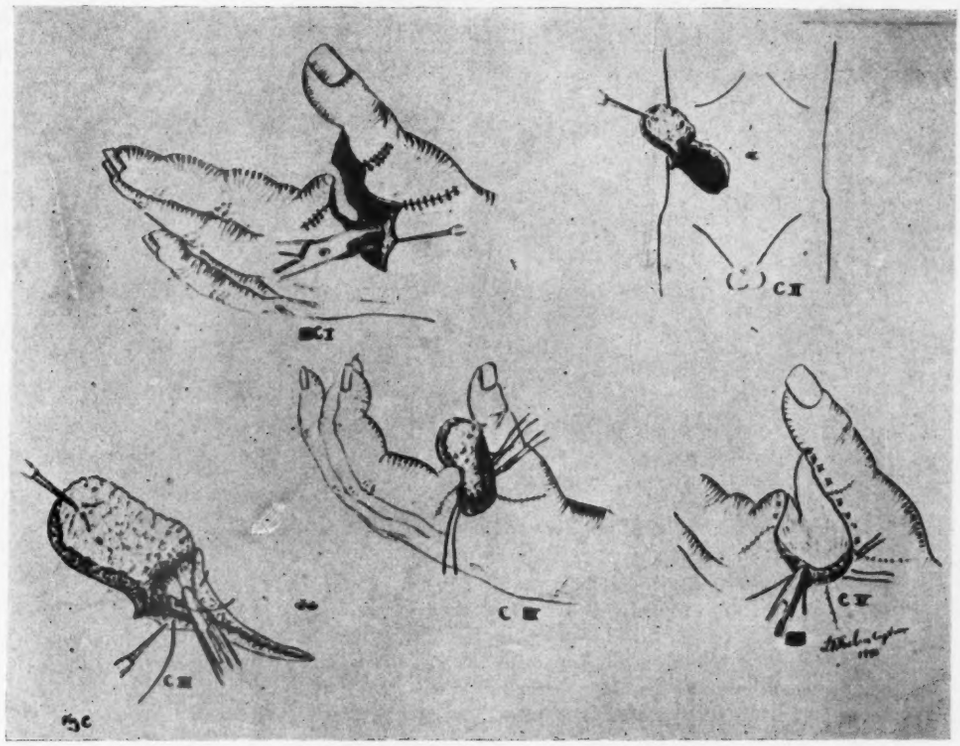


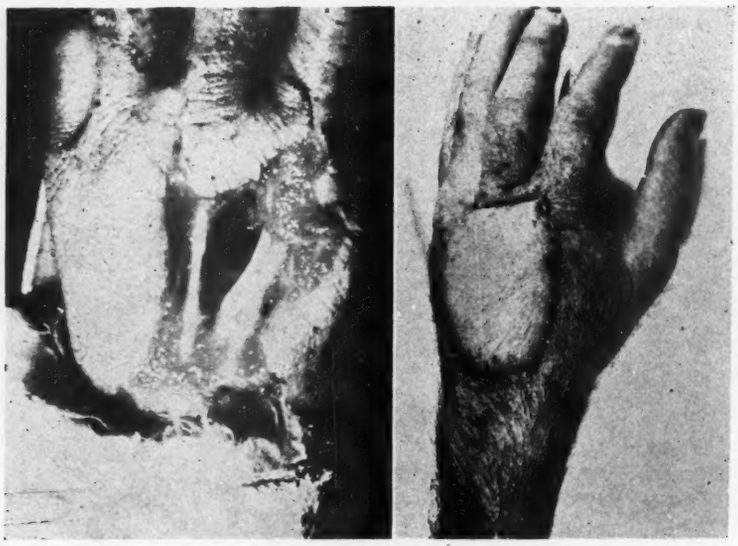
Fig. 3. Illustrations showing the technic of flap application. CI shows the hand defect being decreased in size. CII shows the abdominal flap being raised, all layers of the fat down to Scarpa's fascia. CIII illustrates the closure of the abdominal donor site prior to application of the flap. CIV demonstrates the placing of deep sutures from the fatty underside of the flap to the depths of the wound of the hand. CV shows the final closure of the flap, using the skin subcutaneous suture described in Figure 5.

"pasted" by the gum acacia technic[1] on the superficial "silent" part of the wound, where there were no exposed tendons or bones. After seven days, when the graft was firmly taken, the flap was then sutured into position to cover the rest of the defect. It was customary at the first stage to raise and delay the flap on the thigh.

OPERATIVE TECHNIC

Hand Flap. After the hand defect was débrided and perhaps decreased in size, a tourniquet being used to get a bloodless field, a pattern was made by placing a piece of sterile paper or lead foil over the wound and cutting it to shape. The hand was brought over to the abdomen so that the direction and the size of the flap, including the pedicle, could be marked out on the abdomen. The hand was then withdrawn and the flap lifted in the manner described. With the flap protected by a layer of gauze saturated in saline, the defect left by the flap raising was partially closed by marked undermining along Scarpas fascia and then sliding or rotating the edges together with little to moderate tension; deep sutures of No. 00 catgut were used. The closure was made up to the base of the pedicle, taking care to avoid constriction of the base. A small uncovered area was always left near the pedicle; this was left open until the final repair. The skin was then closed with cotton or silk interrupted sutures.

The flap was now ready to be sutured to the defect; the hand was brought over to the abdomen again. Suturing of the flap to the hand began with the use of No. 20 cotton sutures running from the skin on the most superior edge of the defect to the underlying fatty tissue proximal in the flap; ties were knotted on the skin edge. To anchor the fatty part of the flap to the deep uncovered structures, progressive layers of No. 00 catgut sutures were placed



A B

FIG. 4. A and B, pre- and postoperative pictures of a severe perforating wound of the hand, requiring a dorsal flap only. At the time of flap attachment, the wound was decreased in size by undermining. About one-fifth of the third metacarpal was removed at the time of débridement. The entire second metacarpal was exposed in the wound and was also fractured. While the dorsal second and third tendons were exposed, the patient could perform well with the second finger and have flexor motions with the third finger after the flap was attached and the wound healed.

from the fatty underside to the depths of the defect, obliterating the dead space. It was often difficult to find a good suture hold in the depths of the wound, but all attempts were made to have the fat in direct contact with exposed bone and tendon. At this time a narrow rubber tissue drain was placed deep in the wound to the outside, allowing for any accumulative drainage. The pedicle was inspected last to insure freedom from compression.

Foot Flap. A similar technic was followed for the defects of the foot. The closure of the thigh donor area often presented additional problems, since the skin of the thigh is not as abundant or mobile as the abdomen. Extensive undermining had to be employed. When the flap was very large and the closure impossible, a partial closure was done; the final healing was completed by applying a split skin graft when the flap was detached three weeks later. To insure the proper position of the flap, the foot was first brought over to the thigh and exact size and position marked; while suturing the flap to the foot defect, the assistant held the foot in the correct position at all times to prevent pull on the flap.

Postoperative Fixation. Fixation presented several problems. In hot climates plaster of paris or adhesive was associated with uncomfortable sweating and skin irritability. The hand fixations were ultimately placed in a balanced traction under a Balkan frame, as shown in the Figure 10. Although this required that the patient remain in bed for three weeks, the final results and the great comfort were compensating factors.

A plaster of paris hip spica was the only fixation that was suitable for the foot flaps. The padded spica was applied immediately after the operation, the assistant or the surgeon himself holding the foot in the correct position to insure that there be no tension on the pedicle. Because of the abnormal position of the foot and the weight of the spica, ample reinforcement of the cast was obtained by adding braces. (Fig. 11.) A window was cut in the cast as soon as the plaster set; this was important

for observing the pedicle and the flap. If, because of shifting the position unknowingly, there was tension on the pedicle, the cast would have to be removed and then reapplied.

Postoperative Course. The only dressing applied to the flap was a layer of boric acid ointment gauze strips; the exposed fatty undersurface of the pedicle was covered in a similar manner. The wounds were inspected each day, the drains loosened and finally withdrawn by the fourth day. There was usually a moderate exudate present from the exposed fatty pedicle and the donor site, but this could be readily cleaned with alcohol and redressed with boric acid strips. While the hand wounds were no problem, the foot defects, because of access only through the window cut in the cast, could not be cleaned far down around the donor sites. However, that seemed to make no difference toward the final results.

The hand cases suffered no discomfort at all from the balanced traction, having freedom of movement without any body encumberances. The foot spica cases complained of severe muscle spasms for two days or so, but responded favorably to morphine or codeine; by the third day the discomfort was minimal. To help the patient move about with his cast, a Balkan frame with handle bars for gripping was set up.

On the twenty-first day after the attachment of the flap, the pedicle was severed in one stage and the defect completely closed. The donor site was completely repaired at this time by applying a split skin graft if necessary. Almost all of the abdominal defects could be closed by undermining. Many of the thigh sites were closed by the combined closure and graft methods.

Anesthesia. Practically all the hand cases were performed under brachial block anesthesia; the abdominal flaps were blocked with novocaine 1 per cent without adrenalin. All the foot flaps were operated upon under procaine spinal anesthesia.

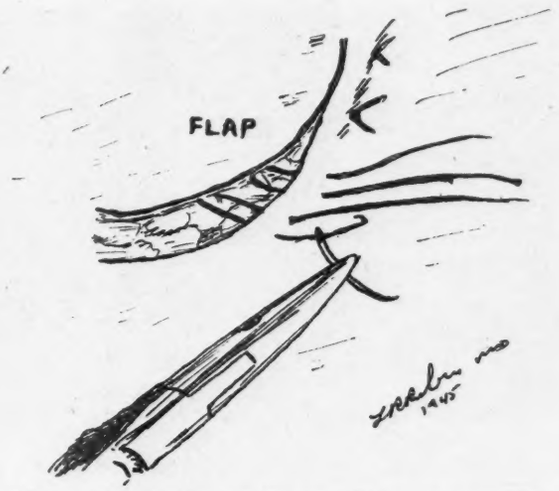


Fig. 5. Illustration of the final skin suture which prevents cutting off of the flap circulation. The defect edge is undermined a bit. The cotton suture goes through the defect skin, taking in all layers up to the fat. The suture then passes through the subcuticular tissues only of the flap and returns to the defect skin in a similar manner as first inserted. When tied on the defect side, there is no cuticular cutting or compression by the sutures.

COMMENT AND ANALYSIS OF RESULTS

There can be little doubt as to the necessity of grafting exposed tendons and nerves with a fatty cover. Since past experiences have shown that such uncovered deep structures became necrotic unless covered early, we attempted flaps even when they were infected. We had hopes of avoiding further destruction. To have procrastinated would have meant months of delay before the deep wounds could heal by secondary intention; during this time infection and necrosis would continue to spread through exposed bones and tendons to contiguous tissue with disastrous results to function.

The principle of Colonel Churchill[5] on multiple blood transfusions and penicillin protection for improved wound healing has enabled us to bring the patient up to optimal condition. We even dared to cover wounds heretofore considered surgically unsound. Every patient had his hematocrit and hemoglobin brought up to normal. During the early stages of exposed tendons and bones and during the first few days after the application of the flap, penicillin (25,000 units) was given every three hours.

A B

FIG. 6. Wound of Achilles tendon, with exposure and three-quarters loss of the Achilles tendon. The tendon was partially necrotic; a flap graft covered the defect. Above the flap can be seen a split skin graft covering a superficial wound defect.

A B

FIG. 7. Severe avulsion wound of dorsum of foot with fractures of second, third and fourth metatarsals. The lateral one-half of the foot was considered a silent area and was covered with a split skin graft .024 of an inch. The medial part of the wound was covered with a heavy flap.

Occasionally, after using the necessary precautions in raising a flap and suturing, we were doubtful about the circulation. These cases were subjected to the fluroscene test, as described by Boyd and Lange.[4] Briefly it consisted of the intravenous injection of 10 cc. of 5 per cent fluroscene and viewing the flap under a special filtered ultraviolet light having a wave length of 3,600 u. If the attached flap showed a color change from deep purple to a golden hue, the circulation was good. Any dark

area in the flap indicated some nutrient obstruction and necessitated suture loosening or replacement of the flap in some way to avoid tissue necrosis.

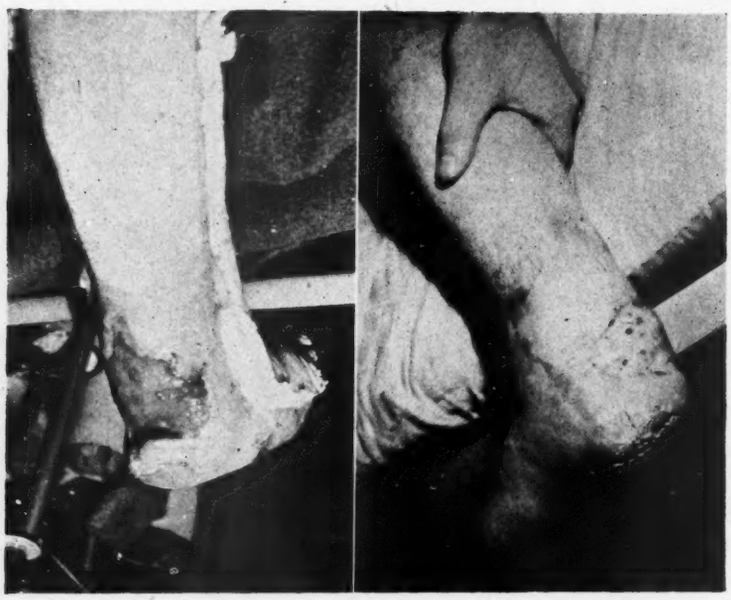
Our early flaps were attached fourteen days before being severed from their donor sites; several patients had skin edge necrosis and in one case about 50 per cent of one flap was lost after severance. After six cases, we extended our attachment time to twenty-one days and thereafter had little trouble. The increase in time also obviated the necessity for partial flap severance and so avoided an extra operation.

Excluding burn cases, we had seventy-eight cases of avulsion wounds of the hands and feet which required grafting. Forty-nine of these cases were deep wounds with exposure of tendons and bones or both. The majority had compound, comminuted fractures associated with the wounds. These forty-nine patients were grafted by the flap graft technic; thirty-four were cases of wounds of the hands, while fifteen foot defects were closed in the similar manner. Of the latter, three flap grafts were combined with split thickness free grafts over the superficial "silent" parts of the wounds. Table 1 shows distribution of the cases and the types used.

Forty per cent of the cases when first covered with the flaps showed some degree of mild cellulitis which cleared within three days. We believed that the presence of a drain into the depths of the wound permitted the drainage of some accumulated material and helped the graft take. Four cases went on to frank pus drainage and had to have clamps inserted under the flap to remove a piece of necrotic tendon or bone; the grafts healed uneventfully thereafter.

Two cases had through and through wounds of the hands with skin avulsion on both dorsal and volar surfaces. With overenthusiasm, we laid a double flap from the abdomen, covering the dorsal and palmar defects of the hand at the same time, as in a sandwich. In each case we had a cellulitis followed by drainage of pus; we had to detach the dorsal flap and allow it to fall in its original bed. In both of these cases, the volar defects were larger in extent than the

FIG. 8. Perforating avulsion wound of hand, with partial loss of #4 metacarpal, both extensor and flexor tendons #4, exposure and fractures of #3 and #5 metacarpals, exposure of #3 and #5 flexor tendons. After admission to the service, the fourth finger was removed and the hand narrowed. A combined dorsal and palmar flap was laid down at the same time. Because of purulent drainage, the dorsal flap was detached allowing sufficient drainage and healing of the palmar flap. When the palmar flap was severed from its pedicle, the dorsal flap was reattached with good healing of the hand.



A B

FIG. 9. Avulsion loss of the os calcaneus with skin defect. The upper one-half of the wound was covered with a split skin graft, .024 in. thickness, and one week later the flap was applied to the defect.

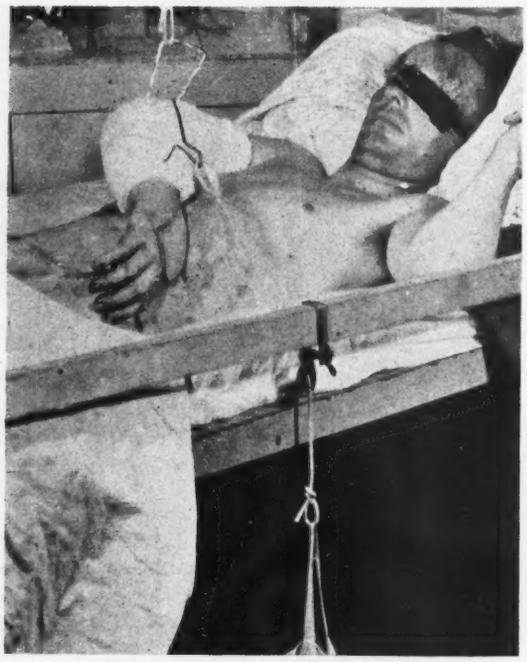


FIG. 10. Balanced hand fixation showing the plaster of paris partial cast, padded, running from mid-arm to about three inches above the wrist. A metal U bar is incorporated in the plaster at the region of the elbow, while from the distal end of the cast, another metal bar extends straight out beyond the hand defect. The bar at the elbow and the distal bar are attached to weights supported by a Balkan frame, giving fixed position and comfort.

dorsal defects. With free drainage established, the volar flaps went on to complete take. After these flaps were severed from their base on the twenty-first day, the dorsals were relifted and immediately attached; these in turn went on to a complete healing.

The foot wounds, as was expected, presented the greatest problems. The cast application had to be meticulously performed to avoid tension of the pedicle. The wounded foot, due to vasomotor instability and the immobile flexed position of the knee in the fixation cast, exhibited mild degrees of congestion, which cleared in every case within a day or so. The greatest problem was the slow breaking down of the cast and the gradual pull of the pedicle, separating the edges of the flap from the wound defect. In two cases, the casts broke within two days, and had pulled the flaps about half way off the defects. These patients were reoperated upon, the flaps lifted, refreshened and reapplied with good results.

All attempts were made to decrease the size of the foot wounds. Some parts of the defects were superficial and could easily tolerate a free graft. In such cases, a thick, split skin free graft, .024 of an inch, was applied one week before the flap was attached. In three of such cases, the thigh flap was raised and resutured in a delaying

Fig. 11. Illustrates the foot fixation cast. The cast is a strongly braced spica from the hips to the foot and contains a window cut out to show the entire flap.

process at the same operation. One week later by the time the flap was sutured on, the split skin was firmly fixed and healing well. (Fig. 7.)

Functional Results. No patient was observed for more than 170 days after injury; most were either discharged to duty or evacuated within ninety days. Our results, therefore, had to be considered from a short time viewpoint.

A review of our Tables will reveal that thirty-four cases involved the hands; of these, eight had severe finger injuries. Where tendons or joints were exposed, the usual results were fingers with varying degrees of limited motion. For those patients with complete fixation of the joints, covering the wounds with a flap retained the fingers in the optimal function with prime consideration given to maintaining the grasp position.

Six cases had wounds of the first web space with partial loss of the adductor, lumbrical and interosseii muscles; we finished with excellent functional retention of prehension (opposition between thumb and finger) in all of these cases.

Three patients lost their thumbs; one had an exposed first metacarpal bone with granulating tissue instead of a web space. The latter was repaired by partially dissecting along the lumbrical and interoseii muscles, freeing the first metacarpal and creating a new web space by placing an abdominal flap in the sulcus; the functional result was good. No attempts were made to build new thumbs for two of our patients who lost their first metacarpals as well as the thumbs.

The flaps over the palm and dorsal hand defects resulted in healed wounds. However, in all of our cases, since tendons were completely destroyed, motion to the fingers supplied by those tendons was lost. Further tendon transplanting would have to be done at a later date.

The remainder of our hand patients having exposed bones showed good grasping functional results after the wounds were healed.

It was difficult to evaluate our feet cases, those who did not have much bony damage were able to walk with no trouble. The patients with loss of bony substance did complain of pain on standing. We have had no follow up on these cases after evacuation to America.

Early Physical Therapy. To ensure early function in hand wounds, a definite functional program was instituted. Since our regular physical therapy department was overburdened, a nurse experienced in

the problems of the plastic-maxillofacial service was assigned to full time care of all hand cases. The treatment concerned itself with passive movements of the fingers as well as constant encouragement in active motion. As soon as the patient was placed in his fixation position for the flap graft, the nurse would spend the necessary time to encourage the patient to use his uninjured but stiff fingers. Four days after the flap was severed from the pedicle and completely sutured over the defect, the patient was started on warm saline soakings, the nurse assisting in active and passive finger movements. (To measure progress, time permitting, goniometer readings were taken.) Individual elastic cuff apparatus were made to give continuous motion to the fingers. Made of plaster of paris, shipping carton baling bands and the cuffs of discarded surgical rubber gloves, this type of traction could be used for any joint by adjusting the lines of direction. The patient could play against the elastic traction and have forced active motion. (Fig. 13.) To start early skilled acts, the nurse would advise and direct the patients on all kinds of games which required the use of fingers.

SUMMARY

1. Forty-nine cases of flap graft closures were performed for deep wounds of the hands and feet, with good functional results.

2. The very early cover of exposed infected tendon and bone is advocated by the use of this technic.

3. The flap graft technic is quick and sure of take in covering wounds of the hands and feet with a fat-containing skin cover.

4. The principles of multiple blood transfusions and penicillin therapy are believed to be important adjuncts in the graft take.

5. Early physical therapy for optimal function is a full time job for a trained nurse or assistant who understands the problems.

The author wishes to thank Colonel George Dixon, Major Arthur Weinberg and Captain Benjamin Hoffman for their assistance and advice in this series of cases; Sergeants Schwone and Ryan for their tireless labors in doing dressings and making mechanical apparatuses.

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SPLINTS AND CASTS IN THE TREATMENT OF WAR INJURIES

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NO one will question that the availability and proper use of splints and casts in the treatment of war injuries are important factors affecting morbidity and mortality. It is also a fact that many of our doctors who in civil practice rarely or never had occasion to apply a splint became familiar with them in the course of their war experiences. What happened then as regards the use of casts and splints becomes understandable. The suddenly expanded medical corps had to learn the hard way, by trial and error. Mistakes occurred early in the game but with accumulating experience they were avoided, much was eliminated by directive and gradually a good deal of essential standardization crept in.

During the course of four war years in the army medical corps I worked at different times as surgeon in a Clearing Station, Field Hospital, Surgical Hospital, Evacuation Hospital and numbered and named General Hospitals. I soon learned that I had to adapt my civilian fracture experience to the peculiar exigencies of war surgery with its mass production methods, long chain of evacuation, segmented treatment and division of surgical responsibility. Methods of splinting and cast application which had proven valuable at home with one patient under the control of one doctor in one hospital throughout the period of treatment could not in most instances be used for wounded soldiers who were cared for by dozens of different doctors, who faced a long tedious journey which was pretty rough in spots and whose fractures, wounds and extremities were very easily lost sight of in the constant shuffle and change from one hospital to another.

Safety, simplicity and security were the criteria by which proposed splints and casts were judged. It was a matter of the greatest good for the greatest number and a few methods which could be readily standardized and uniformly practiced had to be chosen, regardless of the training or preference of any one man.

Naturally the requirements in one theatre or portion of it differed from those in another and a good deal of flexibility in the approach to the problem had to be preserved. In view of this the subject of splints and casts in the treatment of war injuries can perhaps best be taken up under three general headings: Emergency Splinting, Transportation Splinting and Definitive Splinting, according to the particular echelon of command which is under consideration.

EMERGENCY SPLINTING (BATTALION AID STATION)

Here, right in the so-called "front lines," where the injury was sustained and the wounded man received his first medical aid, there existed, theoretically at least, the golden opportunity to prevent further shock and tissue damage by the intelligent splinting of a major wound. I say "theoretically" for unless one has actually served as a Battalion Aid man or worked closely with them he can not possibly comprehend the variety and extent of the obstacles and difficulties that have to be overcome. Such things as weather (wind, rain, snow, hail, fog, heat and cold) and terrain (mud, sand, rocks, bogs, woods, rivers and mountains) merely add to and complicate the mortal hazards of mines, booby traps, barbed wire, strafing, shell and small arms fire which Battalion Aid workers had to face. Then there were such tactical factors as rapid movements forward or back, communica-

Fig. 1. Improvised shoulder spica for compound badly comminuted elbow fracture. Patient ready for sixty mile evacuation from clearing station the morning after surgery. This illustrates an error in cast technic which was not uncommon in the early days of field operation. The forearm should have been much lower and closer to the body so as to avoid interference with an overhanging stretcher; Maktar, Tunisia, February, 1943.

tion, transportation and supply which were constantly changing.

It was one thing to find a wounded G.I. at night—for the largest part of this work had to be done under cover of darkness—and quite another to apply an adequate splint in the field and carry a 175 to 200 pound soldier back to our own lines. Now as a matter of fact regulation army halfring splints were usually available in the Battalion Aid Station. Our medical corps men were well trained and highly proficient in their application, and they used them whenever it was humanly possible to do so.

Of course, there were occasions when, due to extraordinary circumstances, regulation splints were not to be had in the field. In a number of instances clever improvisation by Battalion Aid men achieved effective splinting. The soldier's rifle was sometimes tied alongside his broken leg with his belt and strips torn from his clothing; or a broken arm was swathed to the body with his blouse. Sticks and boards were similarly pressed into service in

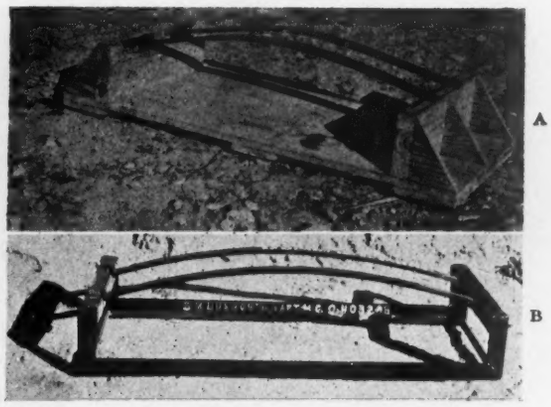


Fig. 2. A, Goldthwaite frame improvised in the field from crates and spring leaves of a jeep; Arzew, Algeria, November, 1942. B, streamlined version of same quickly welded by an ordnance outfit from scrap metal in the field; Feriana, Tunisia, April, 1943.

emergencies. These were recognized as purely stopgap and temporary expedients but they were preferable to no attempt at immobilization and they reflected credit on the stretcher bearers.

Plaster was not employed forward of Clearing Stations and Field Hospitals where the primary major surgery was done. Not only was it physically impracticable but it was believed that wounds should not be encased in plaster until they had been rendered surgically clean. So in World War II our regulation army halfring splint (successor to the Thomas splint) proved itself a God-send to men in the Battalion Aid and Collecting Stations. They had it, they knew how to apply it and they used it. There can be no doubt of the great number of lives and limbs which were preserved by this simple apparatus.

TRANSPORTATION SPLINTING (PRIMARY SURGICAL INSTALLATIONS

In this war most of the primary surgery was done in Surgical, Field or Evacuation Hospitals and it was in these installations that more adequate methods of splinting had to be devised for purposes of transportation. Here was the first opportunity to employ a material which could readily be adapted and molded to the needs of the individual case. When the pressure was on, patients with fractures were operated

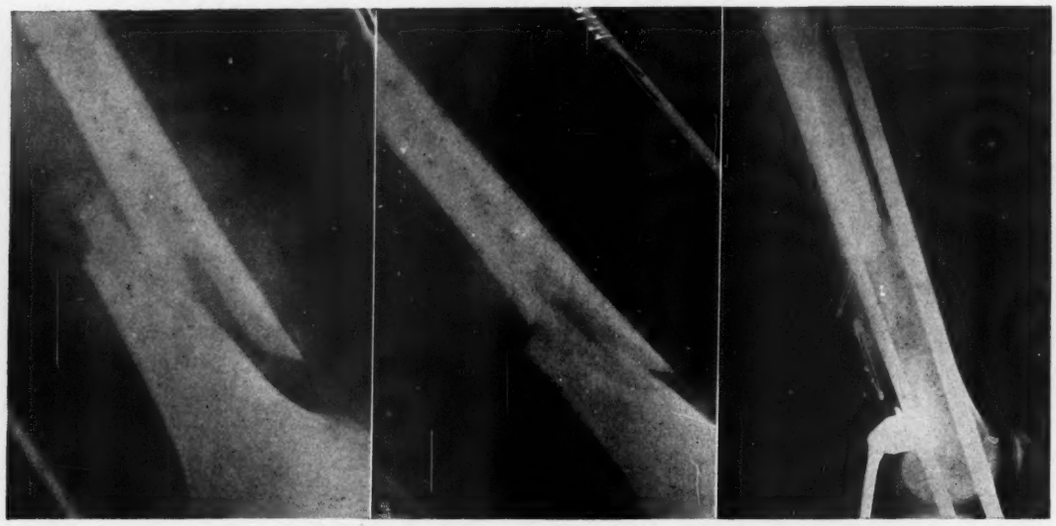
A B

FIG. 3. A, simple fracture of lower third of humerus after three attempts at closed reduction and external splinting. B, same after open reduction and internal splinting in the Zone of Communication.

upon and evacuated within twenty-four to forty-eight hours and they were usually at a hospital in the Zone of Communication for more definitive treatment within an added three to five days. So the halfring splint was in most instances replaced after surgery by some simple form of plaster splint. As it was realized that his cast would usually be removed upon the patient's arrival at a hospital further back, it was not elaborated upon nor was valuable time lost in an attempt to secure anatomic reduction of a fracture.

Great attention, however, was paid to certain fundamental points. All casts were required to be well padded, especially over bony prominences such as tuberosities, condyles and malleoli. As has been previously stressed,[1] the unpadded cast technic, while efficient in certain skilled hands, has no place in field surgery. A corollary to this rule was the requirement that all circular casts and circular dressings about an extremity be split right down to the skin immediately after application. The importance of this simple precaution was attested by several extremities which came to amputation solely as a result of circulatory interference from swelling and edema beneath an unsplit circular dressing. A rough line drawing in indelible pencil on the cast outlining the fracture with a few pertinent notes as to times of injury and treatment, by whom treated and the presence of additional injuries was of great value to physicians under whose care the patient subsequently came. *X*-rays and medical records were not infrequently lost or separated from the patient, and the added time taken to record on the cast itself the essential data mentioned was well spent.

Fractures of the humerus were usually immobilized in a shoulder spica with the arm down and forward across the chest so as not to obstruct the aisle of a crowded hospital train, plain or ship and not to bump against an overhanging bunk or stretcher. (Fig. 1.) Special apparatus and equipment was frequently lacking in these forward installations and shoulder spicas were commonly applied with the patient's back, shoulders and head supported on a broomstick placed longitudinally on the table or stretcher beneath his spine. A modified Goldwaite frame, however, could easily be improvised (Fig. 2) and it facilitated the procedure considerably. Exceptions had to be made when chest complications contraindicated the use of a shoulder spica. In such cases anteroposterior "elephant tusk" plaster splints were used. These extended the full length of arm and forearm and across the front and back of the chest. They were held in place with bandages, swathes or a modified Velpeau. The hanging cast and modifications of it, which were employed in fixed hospital installations in the rear, were used early in the war by field units but were later discarded



A B C

FIG. 4. A, half ring splint with wire traction for supracondylar fracture of femur. B and C, same, showing improved position as the result of pressure bandages applied in the half ring splint.

in favor of the shoulder spica as they provided insufficient immobilization during transportation and patients complained of pain and discomfort.

A simple circular cast below the elbow sufficied for most fractures of the radius or ulna; if both bones were broken, the cast was run up high on the arm which was then placed in a sling. Fractured carpals, metacarpals and phalanges were evacuated either in a simple cast or with basswood splint protection, although occasionally when work was not pressing a traction splint of one form or another was applied.

Pelvic fractures were encased in a double hip spica. Better immobilization was obtained by extending this cast from the lower chest all the way to the toes, with hips and knees in 10 to 15 degrees flexion. This made a heavy bulky cast but one in which the patient was safe and comfortable. Care was taken to window the abdomen and perineum widely to provide for possible distention and bedpan facility.

Conventional types of body casts were used for the transportation of spine injuries from forward installations. Due to the frequency of associated injuries of chest, abdomen and extremities, however, many compromises in the choice and form of splint had to be made.

In the North African campaign, due chiefly to British enthusiasm, considerable interest was evoked in the Tobruk splint for fractures of the femur and knee. Theoretically, this type of splint permitted more comfortable transportation than the hip spica for both the patient and his stretcher bearers. The patient could sit up and the cast was relatively light. Also, it did not protrude beyond the limits of the stretcher. Essentially this method consisted of traction in a halfring splint with a long posterior mold and a light plaster shell from toes to thigh.[1] However, after a reasonable trial by experienced personnel it was discarded in favor of a well applied spica. In my experience the spica provided far better immobilization of the fracture and greater comfort to the patient. One type of splint was about as easy (or hard) to apply as the other. The spica was kept low on the pelvis by tying in the well leg above the knee. A transverse wood strut was wrapped into the cast just above the knees. This braced the spica and was also of great use in lifting and turning the patient. It was placed on the back of the cast for greater solidity and did not interfere with the bedpan since it was well below the perineum.

Fractures of both bones of the leg were put in a circular toe-to-thigh cast with the knee in 10 to 15 degrees flexion and the

Fig. 5. This shows the inadequacy of a half ring splint in the definitive treatment of massive shattering fractures of the femoral shaft; a spica is preferable.

foot at 90 degrees. A below-the-knee cast sufficed for most single fractures of either tibia or fibula, for ankle and for foot fractures.

While the value of adequate splints in the transportation of *fractures* has been taken as a matter of course, their importance in the protection of massive soft tissue injuries of the extremities without bone damage was slow in attaining the general recognition that it deserved. Avulsion, laceration and destruction of large skin areas and muscle bundles occurred not infrequently. Posterior molds, sugar tongs and circular casts proved invaluable in putting these tissues at rest and protecting them from further insult during transit to the rear.

In the early days, following amputation in the field, muscle countertraction was maintained in a regulation halfring splint during evacuation. Later, a much more comfortable and effective method was adopted. The proximal portion of the stump, well away from the wound, was encased in a temporary light circular plaster cuff with a wire ladder loop incorporated in it for muscle stabilization and elastic traction through a stockinette.

DEFINITIVE SPLINTING (ZONE OF COMMUNICATION AND ZONE OF INTERIOR)

In this are included the numbered General and Station Hospitals in the Zone of Communication and named General Hospitals in the Zone of the Interior.

Zone of Communication. For most patients the treatment in these installations was definitive and the methods of splinting used were in many respects those employed in civilian practice at home. Due to the fact, however, that there were such numbers of cases of any one common type of fracture, a certain amount of standardization and mass production in treatment methods was not only practicable but imperative. This again meant in large measure splinting by directive rather than by choice.

FIG. 6. A and B, half ring splint with Kirschner wire traction for fractured femur. C and D, circular cast used simultaneously for severe fractures of tibia and fibula in the same extremity.

The use of any form of internal splint (plates, screws, pins) was frowned upon and discouraged. I am satisfied that this was a good general rule, but I believe that it should have been more flexible and that exceptions could profitably have been made with greater frequency in individual cases in which the surgeon was well qualified and the facilities for postoperative care and rehabilitation adequate. It is doubtless true that the results of internal splinting were not in many instances as happy as those obtained in civilian practice but few men experienced in traumatic surgery will question the advisability, for instance, of an open reduction and internal fixation of a simple fracture of the lower third of the humerus which is stuck in malposition and cannot be replaced by closed reduction. (Fig. 3.)

A B

FIG. 7. A, combined use of circular cast and wire traction for shattered tibia and double fracture of fibula. B, it was possible to improve the alignment by wedging the cast while maintaining moderate traction.

P. T., aged twenty-one, a Field Artillery gunner, sustained a simple fracture of the lower third of the humerus in a jeep accident October 8, 1944. He was treated with a traction cast and three separate attempts were made to improve the position of the fragments by closed reduction under anesthesia. All were unsuccessful. Open reduction, correction of the deformity and internal fixation with a 4 screw Vitallium plate were done on November 11, 1944, in a numbered general hospital in the United Kingdom. At operation, as expected, the fragments were found to be united solidly with abundant callus which had to be removed before reduction was secured.

By having an internal splint applied in the Zone of Communication instead of the Zone of Interior, this lad was saved weeks or months of prolonged convalescence and rehabilitation and the army profited to that extent. Without correction and internal splinting he would have been a complete loss to the services as well as permanently handicapped. So there was, in my opinion, a real need of the internal splint in selected cases certainly as far forward as the Zone of Communication.

In general, good results were obtained in the Zone of Communication by treating fractured humeri with a hanging cast in which were incorporated tapes for suspension and traction or by Kirschner wire traction in a regulation halfring splint. After six to eight weeks the fracture was usually frozen sufficiently for removal of plaster and institution of physiotherapy or for evacuation of the patient in a shoulder spica to the Zone of the Interior.

In the definitive treatment of hand fractures in the Zone of Communication the results achieved seemed poorer than for any other common type of fracture. This was due principally, I believe, to two things: In the first place, the importance of function as opposed to anatomic reduction was not sufficiently understood and generally appreciated. Too much attention was paid to splints and too little to early motion regardless of some bone deformity visible on the *x*-ray. Secondly, all too often these injuries were regarded as minor matters and their treatment was delegated to the less experienced members of the staff.

These small fractures are not dramatic unless one makes them so in his own mind; it was all too easy to apply a cast or a splint and forget about them for a period of weeks. Towards the end of the war, however, when poor results began to collect in impressive numbers, a real effort was made to institute more functional methods of treatment and to make hospital staffs more finger conscious. Splints were then used very sparingly and sometimes not at all.

In the treatment of fractured femora and knees the regulation army halfring splint with Kirschner wire traction was widely employed. Traction was thus maintained until the formation of sufficient callus to permit evacuation of the patient in a double hip spica to the Zone of Interior. This method of splinting permitted the use of accessory measures such as countertraction and pressure bandages to improve alignment and position. (Fig. 4.) It also aided in preserving the function of neighboring joints during the prolonged period of treatment. In some instances, however, comminution of the bone was so severe and extensive (Fig. 5) or the condition of the soft tissues was such that encasement in a plaster spica was mandatory.

Severe fractures of femur, tibia and fibula in the same extremity posed difficult and not infrequent problems. Encasement of the leg in plaster and the application of Kirschner wire traction on the femur in a halfring splint provided a satisfactory solution in some cases. (Fig. 6.)

Ordinarily, fractures of both bones of the leg were treated with Kirschner wire traction in a halfring splint or were immobilized in a toe-to-thigh cast. Occasionally, a combination of the two methods, permitting maintenance of traction and wedging of the cast to improve alignment, was employed. (Fig. 7.)

Zone of the Interior. In the named General Hospitals at home methods of splinting closely approximated those of civilian practice and therefore need no elaboration here. As would be expected, internal splints were more freely employed. By the time the patient arrived in the United States his physical condition, local and general, was often well stabilized and his morale improved. Facilities for treatment and after-care were in some respects more adequate and better organized, and certainly not least in importance was minimization of the time element as an essential factor affecting the type of treatment chosen.

SUMMARY

The use of splints and casts in the treatment of war injuries varied according to the particular echelon of command in which they were required. In general, emergency splinting was effected with the regulation army halfring splint. For transportation following primary surgery plaster was almost universally employed. Definitive splinting in the Zone of Communication was accomplished by use of the halfring splint or plaster, frequently by a combination of the two. Internal splinting was, for the most part, reserved for the Zone of the Interior. Two points deserve especial attention; the use of splints in the protection of extensive soft tissue injuries during transportation and the abuse of splints in the treatment of fractures of the hand.

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FRACTURES OF THE UPPER EXTREMITY*

A REVIEW OF EXPERIENCES IN WORLD WAR II

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THE tremendous number of fractures, simple as well as compound, which occur during war, provides an unusual opportunity for comparing the applicability, safety and reliability of different methods of fracture treatment. Although the treatment of fractures under battle conditions on land and on shipboard must of necessity differ from treatment in ordinary life, the basic principles of management apply to both types, and lessons learned during World War II should prove of great value during the years of peace.

Experiences in this war have re-emphasized the importance of mobility as the predominant requirement for the upper extremity in contrast to stability for the lower. Proper joint function should be the objective even at the expense of shortening of the bone. All joints of the upper extremity are closely related and the motion of all must be subservient to the proper functioning of the hand.

Coincident with the development of early ambulation following surgery in civilian life, an intensive reconditioning program for the sick and wounded with the patient as his own physiotherapist was instituted in the Army. Ambulatory treatment was greatly stressed under this program and was particularly applicable to patients with fractures of the upper extremity, who were treated in this way whenever possible.

The war has also afforded a testing ground for new technics in the treatment of upper extremity fractures. Experience has proved the efficiency of the "hanging cast" in treating most humeral fractures, has emphasized the necessity of splinting fractures of the hand in the position of function, and by providing an unexpectedly large number of carpal scaphoid fractures has crystallized opinion concerning the management of this injury.

THE PROBLEM OF COMPOUND BATTLE FRACTURES OF THE UPPER EXTREMITY

Compound fractures sustained in battle, unlike simple fractures, differ greatly from those in civilian life; they show greater comminution, more extensive soft tissue wounds with a higher percentage of retained clothing and foreign bodies, and their treatment is often complicated by the necessity for evacuation over long distances. These differences have given rise to a policy, advocated by almost all army and navy surgeons, of leaving wounds open following primary surgery.

During the first years of the war the majority of compound fractures were treated by the "closed plaster" technic used by Trueta in the Spanish Civil War.[1] His program stressed prompt surgical treatment, cleansing of the wound, a thorough débridement, provision for drainage and immobilization in plaster until healing occurred. The method was enthusiastically endorsed by many surgeons. It was found especially useful when traction methods requiring weights and pulleys could not be used, as on shipboard.[2,3,4] At the beginning of the war Kirk[5] questioned whether it was possible to maintain reduction of fractures of the shafts of long bones by this method unless the fracture was transverse. The doubt was well justified; fractures of the femur and many fractures

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of the tibia were shown to require traction methods.[6,7,8]

Fractures of the upper extremity, however, were better suited to the closed plaster technic. By using a hanging cast the advantages of both traction and "closed plaster" were utilized.[9,10] Fractures of the radius and ulna could usually be maintained in position by plaster alone or by the insertion of pins incorporated in plaster.[11,12,13] Although position and alignment of bone might be maintained by "closed plaster," in many fractures of the upper extremity soft tissue deformity was great. The introduction of reparative surgery by Churchill,[14] in which the wounds were closed by delayed primary suture within ten days after injury, converted a compound fracture into a simple fracture, minimized scarring and saved many hospital days. Many reports confirmed the value of this program. MacFarlane[15] recorded seventy-four cases of compound fractures of the upper extremity closed on an average of 7.6 days following primary surgery with success in 90 per cent. Kergin[16] stated in 1945 that early wound closure was the most significant advance in surgery in this war. The importance of thorough débridement as an essential feature of both the closed plaster technic and delayed primary suture cannot be overemphasized. The new chemotherapeutic agents were an important part of this program although their exact value has not been determined.

Internal skeletal fixation for the treatment of compound fractures was used very rarely in this war. Experience showed that more conservative methods were preferable under battle conditions.[17] Hampton[18] reported its use in 332 selected cases, but only ninety-eight of these were fractures of the upper extremity and only in the exceptional case is this method required. In the restoration of the articular surface of a major joint internal skeletal fixation is often indicated.

External skeletal fixation in the treatment of fractures in the armed forces has been advocated by Shaar,[19,20] who reported the successful use of the Stader splint in 110 consecutive cases of acute fracture treated at the Naval Hospital in Philadelphia. Thirty-one of these were fractures of the upper extremity. Bradford and Wilson,[21] reporting on the use of the Roger Anderson and Haynes apparatus in the American Hospital in Britain, found that this technic was rarely indicated for bones of the upper extremity. External skeletal fixation was not found useful under battle conditions;[3,17] it was time consuming, not applicable to large numbers of casualties and was reported to give a high incidence of infection about the pin sites.

Compound battle fractures are often complicated by nerve and arterial damage which greatly influences the treatment; such injuries are especially common in upper extremity fractures. Nerve injury was found in 40 per cent of a series of gunshot fractures of the humeral shaft, radial in 33 per cent and median in 7 per cent.[10] Treatment of the nerve injury often assumes first importance. The early repair of nerves is essential for good results; patients should be transported to neurosurgical centers as soon as possible for specialized surgery. Overzealous splinting of the wrist and fingers in extension for radial nerve injuries may result in fixation in that position.

Circulatory impairment was due not only to damaged major vessels but also to constriction by tight plaster casts, to tamponade of circulation from unsuspected hemorrhage beneath the deep fascia[22] and to vasospasm.[23] Splitting plaster casts through their entire length was necessary for the prevention of constriction in recent injuries.[24,25] Where hemorrhage was present, it was necessary to split the deep fascia in order to release tension and control bleeding. Vasospasm was treated by procaine hydrochloride blocks of the regional sympathetic ganglia.[23] By employment of these methods gangrene or ischemic paralysis was often prevented.

In the treatment of compound fractures of the upper extremity complicated by a

burn, Warthen[26] advised a compression dressing covered by a circular plaster cast.

TEMPORARY IMMOBILIZATION OF FRACTURES OF THE UPPER EXTREMITY

In contrast to fractures of the lower extremity, upper extremity fractures were easy to immobilize for evacuation to fixed installations. Most patients with fractures of the humerus, both simple and compound, were adequately transported with the arm near the side.[2,4,10,27,28] This could be accomplished by a circular plaster cast from axilla to wrist fixed to the body by encircling bandages, which could later be converted into a hanging cast by removal of the bandages; or it could be accomplished by a chest pad with a double sling, by a Velpeau type bandage or by a plaster spica with only slight abduction.

It was shown definitely that the hinged arm traction splint (Murray-Jones), advocated at the beginning of the war, should not be used because of the danger of nerve and blood vessel injury from pressure in the axilla.[28] Fractures involving the shoulder joint required a spica. When a spica is used only mild abduction is required. Wide abduction often produces medial angulation and is cumbersome for transportation on airplanes and ships.[4,10,27] Fractures of the elbow are best immobilized at right angles in plaster; and fractures of the forearm by circular plaster including elbow and wrist, or by plaster "sugar tongs."[28]

A study of hand cases evacuated from the South Pacific[24] showed that when immobilizing any portion of the upper extremity it is of the greatest importance to immobilize the fingers only when absolutely necessary and then in the semi-flexed position. Casts used to immobilize the wrist should extend only to the distal palmar crease in the palm, leaving the fingers absolutely free, and should extend to just back of the knuckles on the dorsum in order to prevent edema. Immobilization of the wrist and forearm is mandatory in lesions of the hand. If it is necessary to immobilize the thumb, a position of opposition should be used.

PROBLEMS RELATED TO SPECIFIC BONES

Clavicle. No universally applicable method of treatment has been found for fractures of the clavicle and many different forms of therapy were used during the war. Although non-union of the clavicle is very rare, the accurate reduction of fractures of the clavicle was important in military surgery because minor deformities of this bone cause pain to men wearing a pack or gun.[29] The plaster figure-of-eight splint was widely used. Packer[30] reported the use of a plaster jacket for the treatment of fractures of the clavicle. It extended down to the lower ribs, and was closely applied to the root of the neck and well out to the deltoids. It was trimmed from under the armpits to allow the limbs to hang normally without circulatory embarrassment. The weight of the cast was carried on the proximal fragment rather than on the shoulder by means of a thick pressure pad. The author stated that the soldier was able to wear normal clothing over this dressing and could return to duty in a few days. Immobilization was carried out for four to six weeks. Intramedullary pinning for fractures of the clavicle, introduced by Gordon Murray,[31] was evidently not considered necessary in most cases as judged by the paucity of reports of its use in military service.

Compound fractures of the clavicle were well handled by a plaster shoulder spica which did not need to include the elbow. If the shoulder joint is involved, the arm should be abducted 60 degrees and held about 45 degrees forward to the plane of the body.

Humerus. Almost all fractures of the humerus, including those of the upper third, were best treated with the arm near the side; wide abduction was often harmful because it caused considerable medial angulation of the fragments.[6,10,27] The efficiency of the hanging plaster cast for treating fractures of the humerus was amply dem-

onstrated in the services.[2,6,9,10,11,12,13,22,29] Its limitations and dangers were also forcibly brought out. Because traction of the cast may result in overpull, frequent *x*-ray examination must be made during the early part of treatment. While reduction may be accomplished by the use of the cast alone in many cases, the hanging cast should not be *depended* on for reduction; and unless *x*-rays show a satisfactory position within a few days, further treatment is necessary. All authors emphasized the importance of early shoulder exercises when the hanging cast was used.

Compound fractures as well as simple were adequately managed by the hanging plaster cast, which proved to be the simplest and most efficient method of handling these injuries in the combat zone. In cases of bone loss, however, the plaster spica should be used to prevent distraction.

Compound fractures of the humerus are associated with a high incidence of nerve and blood vessel damage, which must be carefully treated along with the fracture. When circulatory damage is present, plaster casts should not be applied until the danger of ischemia is past.[23] Radial nerve damage is extremely common. It is important when splinting the wrist and fingers in radial nerve injuries to make the splints removable so that the fingers and wrist can be moved throughout a full range of motion several times daily. If this is not done, considerable joint stiffness may result.

Reports from civilian surgeons during the war have emphasized the value of early mobilization in the treatment of fractures of the upper end of the humerus in preventing stiffness of the shoulder joint.[32–36] Although this is of greater importance in the older age groups than in those of military age, early mobilization should always be used in such fractures when practicable. If there is no displacement, it is sufficient to treat the fracture by an axillary pad with the arm fixed to the side of the body, the elbow free and the wrist supported by a cuff suspended from the neck. In fractures of the upper end of the humerus which are difficult to reduce by manipulation and traction the short upper fragment is usually abducted and rotated outward, while the pectoralis major and subscapularis tend to draw the proximal end of the distal fragment inward and upward. In such fractures open reduction may be required. Key[33] fixed the fragments after reduction with two Kirschner wires, leaving one inch of each protruding from the skin to be removed later. In severe fracture dislocations which can not be reduced by closed methods, internal skeletal fixation is required.

Although ambulatory methods of treating fractures of the humerus were always preferable, bed treatment was sometimes required because of associated injuries, and this often necessitated traction methods. Webster,[37] of the Navy, described an apparatus for securing lateral traction in the upper extremity which could be easily assembled and applied in both Army and Navy installations. Either skin or skeletal traction could be used. Traction may be applied to a hanging plaster cast, when it is necessary for the patients to remain in bed, by means of weights suspended over a pulley and attached to a loop incorporated in the plaster at the elbow.

The value of pronation of the forearm in correcting the varus deformity often associated with fractures of the lower end of the humeral shaft was emphasized by Kelly and Riley.[38] They showed in experimental fractures that pronation of the forearm relaxed the spasm of the powerful pronators attached to the medial condyle and responsible for lateral angulation if the forearm is supinated. Fractures of the lower end of the humeral shaft should be immobilized with the forearm in pronation. This position should be maintained, however, only until callus is firm enough to prevent displacement. Then the midposition should be assumed in order to reduce elbow stiffness. A careful analysis of a group of these injuries in the R.A.F. emphasized the importance of an organized rehabilitation program in overcoming elbow stiffness following humeral fractures.[39]

An interesting and refreshing article concerning fractures of the humerus was reported in the *St. Bartholomew Hospital Journal* entitled "The Place of Organized Elbow Lifting in Treatment of the Fractured Humerus."[41] The patient was a British squadron leader with a complete detachment of the greater tuberosity. Active motion of the elbow was begun under water on the fourth day. Starting on the ninth day the patient was forced to use the injured arm to raise all beverages to his mouth. The times of treatment corresponded to the exact time of the opening of the bar. Half pints only were used during the first few days but these were increased. Progress was astounding. The patient got his arm as high as the shoulder by the eleventh day and was discharged to ground duty in two weeks.

Elbow. Shands[29] stated that conservatism was advisable for military surgeons treating extensive comminuted and displaced fractures of the elbow since conservative methods give the greatest number of good results in the hands of the largest number of surgeons. He advocated open reduction with internal skeletal fixation only for the displaced single condyle which could not be held in proper alignment by simple methods, and for certain olecranon fractures. Before resorting to open reduction, skeletal traction should be tried with a Kirschner wire through the proximal ulna just distal to the tip of the olecranon. In fractures of the capitellum with a large fragment, reduction may be possible by direct pressure while the forearm is pronated, adducted and flexed slightly. If reduction is impossible, the fragment should be exposed by arthrotomy and either fixed by screws or removed.

Because compound fractures of the elbow joint often result in ankylosis, Devine[41] advised immobilization in the position best suited to the occupation of the patient. Mobility of the elbow is much more important than stability, however, and everything possible should be done to gain some elbow motion, however slight. Forceful manipulation of stiff elbows is rarely successful. A better final result was usually obtained with a program of continued, persistent and painstaking active motion.

The development of ischemic paralysis was encountered all too frequently in fractures about the elbow.[10] In some instances it was due to tight, unsplit plaster casts. Incisions through the deep fascia, with the release of tense collections, was helpful in some cases. When traumatic vasospasm was present, procaine hydrochloride block of the stellate ganglion was effective in improving circulation.

Head of the Radius. Fractures of the head of the radius were exceedingly common in military service and frequently resulted in traumatic arthritis with limited painful motion.[29,42–47] There has been considerable controversy as to whether treatment by immobilization or by excision of the head is preferable. Because both methods left much to be desired Mason and Shutkin[43] tried immediate active motion associated with local heat with good immediate results. By starting early active motion it was hoped that small uncontrollable fragments of the head would be moved across the fixed uninjured surface of the humerus and would attain the best functional position. Only fractures with little displacement were treated by this method. Postlethwait[46] also tried the immediate active motion treatment in a small number of radial head fractures without displacement and reported encouraging results.

Most writers advised operation with excision of the head for fractures with displacement, although radial deviation of the wrist, lateral instability of the elbow, and excessive calcification about the elbow joint may complicate the operation in some instances. In an analysis of 110 radial head fractures in the R.A.F., Meekison[45] found that of thirty-two not operated on only three regained complete movement; in seventy-eight patients operated on good motion was regained in almost all. If excision is performed, it must be done early, preferably on the day of fracture, before

damage to the capitellar articular surface has resulted. At operation the injury is usually found to be more extensive than was anticipated. Old untreated fractures present a much more difficult problem because of the organized transudate within the capsule, and poor results were obtained by all methods.

Olecranon. Although some fractures of the olecranon with separation may be successfully treated by keeping the arm in complete extension, the danger of fixation of the elbow in this position often requires open reduction and internal skeletal fixation, either by absorbable or non-absorbable material.[47] When there is comminution of the articular portion, arthrotomy is indicated to remove the small articular fragments. Shands[29] warned against the removal of too many fragments or the complete excision of the olecranon process. Civilian surgeons [48,49,50] reported the use of longitudinal pin and screw fixation for the treatment of these fractures, using materials of sufficient length to engage the cortex of the distal fragment. The following advantages were given: better reduction, better retention and shorter disability with early recovery of motion.

Monteggia's Fracture. Full function following the Monteggia fracture is rare. The common type is a fracture of the ulna about three to four inches below the tip of the olecranon associated with anterior dislocation of the head of the radius. Early reduction by closed methods may be successful. If not, open reduction with plating of the ulnar fracture is necessary. The elbow should be immobilized in a position of flexion with the forearm in supination. Suture of the orbicular ligament and the construction of fascial slings, which may be necessary in old cases to hold the dislocated head in place, is a procedure to be done only by the specialist.[29]

Radius and Ulna. Because fractures of both bones of the forearm are technically very difficult to reduce and maintain in good position and because fractures of the middle third of the radius not uncommonly result in non-union, fractures of the forearm presented an important problem to the military surgeon.[47,51,52] The radius is usually displaced towards the ulna because the muscles on the radial side are stronger. It should be remembered that the ulna is important in movement and stability of the elbow, while the radius supports the hand, and that in rotary movements the ulna is fixed while the radius moves.

In fractures of the radius proximal to the insertion of the pronator radii teres the proximal fragment is supinated by the unopposed action of the biceps and supinator; these fractures should always be reduced and immobilized with the forearm in full supination. In fractures below the insertion of the pronator radii teres the pronators balance the supinators and the upper fragment is held in midposition; these injuries must be immobilized with the forearm in the midposition.

In oblique fractures of either one or both bones, shortening is frequent during immobilization in plaster. When both bones are fractured, shortening of the radius with ulnar angulation is the usual deformity. In these injuries some form of skeletal fixation is usually necessary. A good method, and one frequently used, was the insertion of one pin or wire through the proximal ulna and one through either the distal radius and ulna or the metacarpals with incorporation in plaster. This method was especially useful in treating compound fractures of both bones of the forearm if they could not be held by plaster alone.

When treating forearm fractures one should keep in mind the principle that all upper extremity therapy is directed chiefly toward the proper functioning of the hand. Compound fractures of the forearm may be especially destructive because so many structures—nerves, tendons, blood vessels—vital to the functioning of the hand are packed into a small space and may be injured. Causalgia is a frequent complication. Overzealous treatment of the fracture to the exclusion of other injuries may lead to a stiff and crippled hand.

Several authors [53–54] commented on the infrequency of fractures of the lower end of the radius in the military service. Many so-called Colles fractures were above the Colles level. Joldersma[57] pointed out the usefulness of prolonged traction as advocated by Böhler in the reduction of fractures about the wrist. He used fixed traction with Chinese finger traps and a 15 pound pull for fifteen minutes. By this method he was able to reduce accurately almost all injuries in this region. The Cotton-Loder position of flexion and ulnar deviation may result in considerable stiffness. If this position is necessary for a time to hold the fragments in place, it should be changed to a neutral position as soon as the fragments are stabilized. Immobilization by moulded plaster splints should be carried out for three to five weeks. Opinions were divided as to the best anesthesia; some favored local, and some general.

Carpus. Fractures of the carpal scaphoid proved to be a tremendous problem in the armed forces. A much larger number of cases was encountered than had been anticipated, and because treatment was necessarily long and because most of these patients could not be treated while on a duty status, an enormous amount of time was lost. For these reasons and because this fracture lends itself well to analysis, there were more reports of carpal scaphoid fractures in World War II than of any other fracture of the upper extremity.[45,53–56,58–65] In this respect fracture of the carpal scaphoid was the "march fracture" of the upper extremity. It was encountered much more frequently in the service than Colles fracture. During two years service in the Canadian Army McKim[56] encountered 125 scaphoid fractures and only eight Colles fractures. In a series of 110 fractures of the wrist Shands found 80 per cent to be fractures of the scaphoid, and Obletz[53] reports approximately the same incidence. This high frequency was attributed to the age and sex of members of the armed forces; fractures of the carpal scaphoid are found almost exclusively in vigorous young males, and only rarely in the old and almost never in women. It is thought that the strong forearm and wrist muscles of young males resist hyperextension and project leverage more distally, causing a fracture of the scaphoid rather than a Colles fracture.[45,53]

Most of the fractures occur through the midportion or waist of the scaphoid. Of 257 cases in the Canadian Army reported by Dickinson and Shannon[64] it was found that 75 per cent were through the waist, 15 per cent were through the proximal pole (proximal one-third of the bone), and only 10 per cent involved the tubercle. These authors expressed the opinion that the degree of radial deviation of the wrist at time of injury determines the segment of bone fractured; the more radially the wrist is deviated the more distally the bone is fractured.

Although union is slow, good results can be obtained if the diagnosis is made early and the proper treatment instituted. Diagnosis is easy for one who is familiar with the injury. There is the history of a fall, pain on motion of the wrist, tenderness and swelling over the navicular in the "snuff-box" area, increase of pain on passive motion of the thumb, and pain on percussion of the tip of the thumb. Diagnosis is confirmed by *x*-rays which, besides routine views, must include oblique views and anteroposterior views with the wrist in ulnar deviation. If these supplementary views are not taken, many scaphoid fractures will be missed on the first *x*-ray. Even with these views some fractures do not appear on the films for two or three weeks. If the clinical examination indicates that a fracture is present and the first *x*-ray is negative, the injury should be treated as a fracture for three weeks and another *x*-ray taken. A negative *x*-ray after three weeks is proof that no fracture exists.

Most writers have expressed the opinion that the treatment of recent fractures of the body of the scaphoid has been solved; it depends on prompt diagnosis and early institution of prolonged immobilization in the proper position. McKim[56] reported a

series of 125 scaphoid fractures so treated without a single case of non-union, and Dickinson and Shannon[64] reported 116 cases of fractures of the waist treated in like manner without a non-union. Tubercle fractures almost always heal within three to four weeks by simple immobilization of the wrist. But proximal pole fractures, because of the poor blood supply, occasionally result in non-union even if immobilized early. These fractures, fortunately, are rare.

The generally accepted treatment for fracture through the body of the scaphoid is that recommended by Soto-Hall.[65] The wrist is immobilized by a plaster cast in about 20 degrees dorsiflexion and full radial deviation with the thumb carried into full abduction. The plaster extends from just distal to the elbow to the middle of the thumb nail and to the distal crease in the palm. Immobilization must be continued until bony union occurs, a period averaging about three months.

While the treatment of fresh fractures of the scaphoid was generally agreed upon, there was controversy concerning the treatment of delayed union and non-union. Delayed union and non-union are usually due to avascularity and necrosis of the proximal pole. Obletz[53] stated that avascularity is often temporary and that union will occur if prolonged immobilization is carried out. In cases showing improvement by *x*-ray, prolonged immobilization—sometimes as long as twelve to sixteen months—is recommended. Others[58,59,65] do not concur in this belief, but advise surgery if union has not taken place in four or five months. Drilling of the ends of the fragments, bone grafting procedures and excision of the proximal fragment or the entire scaphoid have been recommended with special indications for each.

Soto-Hall[65] reported luxation of the lunate in 12 per cent of scaphoid fractures. If reduction is possible, the wrist should be immobilized in slight volar-flexion for four weeks. If reduction cannot be accomplished by closed means, the lunate must be excised.

Metacarpus and Phalanges. As stated by Mason,[66] "Nature has developed in the hand a finely coordinated motor and sensory organ which has made possible our present civilization." The importance of making all other motions of the upper extremity subservient to the proper functioning of the hand has been amply demonstrated during World War II. In injuries of the upper extremity the fingers should be immobilized only when absolutely necessary in order to avoid permanent stiffness. Casts which are applied for immobilization of the wrists should extend only to the distal palmar crease so that full finger motion may be maintained. In immobilizing hand injuries the concavity of the palm must be preserved, avoiding "flat" splinting.[67]

Metacarpal fractures are usually just proximal to the head and, if displaced, result in dorsal angulation and recession of the metacarpal head into the palm. The spasm of the interosseous muscles, which is unopposed, maintains the flexed position of the distal fragment. In reduction it is necessary to flex the metacarpophalangeal joint to 90 degrees, which eliminates the interosseous spasm. Splinting the fingers in extension or the entire hand about a roll of bandage must be avoided if deformities are to be prevented. Splinting in extension results in a high incidence of contracture of the joint capsule.

Fractures in which reduction cannot be maintained by ordinary splinting require more radical therapy. Skeletal traction applied to the finger of the involved metacarpal was extensively used for these injuries.[68–71] Various materials were used to transfix the bone: towel clips,[69] small Kirschner wires,[70] and intravenous needles.[68,71,72] Traction was usually obtained by means of rubber bands attached to wire loops incorporated in plaster with the finger in a position of flexion. The remaining fingers were left free.

The use of Kirschner wires drilled transversely through the involved metacarpal and into adjacent metacarpals for fixation

following reduction has been reported.[73,74] This method was advocated for the four inner metacarpals only. Single wires were used for fractures through the neck or base and double wires for oblique fractures of the shaft. The hand and projecting portion of the wires were immobilized by a plaster cast which left the fingers free. Active mobilization of the fingers was begun at once and the patient sent to duty in a day or two.

More recently medullary canal wire transfixion was introduced for metacarpal fractures.[75] A short incision is made over the fracture site and a very fine Kirschner wire is inserted into the medullary cavity of the distal fragment, passed through the metacarpal head and through the overlying skin. The fragments are held in alignment while the course of the wire is reversed to the base of the metacarpal. The wire is held in place for two weeks and is removed by a simple skin incision. No external form of immobilization is used. This method has been employed extensively in army orthopedic centers for fixing iliac bone grafts used in treatment of non-union of the metacarpals.

Gunshot fractures of the metacarpals were serious because of frequent tendon and nerve damage and severe shattering of bone with loss of bone substance.[67,76] In many cases skeletal traction is required for the reduction and maintenance of the fracture. Vasospasm is frequent and should be treated by stellate ganglion block with procaine hydrochloride.

Fractures of the phalanges, both simple and compound, were often very difficult to treat.[77] It is even more essential to obtain accurate reduction here than in fractures of the metacarpals. The interphalangeal joints more than any other joints in the upper extremity show a tendency to become fixed after continuous immobilization. Fractures of the proximal phalanx usually result in volar angulation because the interossei pull the proximal fragment into flexion. When reduction cannot be maintained by simple splinting, skeletal traction with the metacarpophalangeal and proximal interphalangeal joints in flexion is required. The healthy fingers must be left free and active motion instituted from the first. In the débridement of compound fractures of the phalanges it is extremely important that all viable tissue be retained.

One of the greatest medical contributions of the war has been the work of Dr. Sterling Bunnell, who acted as civilian consultant to the Army on surgery of the hand. Dr. Bunnell's leadership has greatly stimulated military surgeons and his advice has been of untold value in the reconstruction of many crippled hands of the wounded.

SUMMARY

1. Fractures of the upper extremity in World War II were treated by ambulatory methods.

2. War experience has emphasized that the function of the joints of the upper extremity should be subservient to the proper functioning of the hand.

3. Fractures of the humerus were best handled with the arm near the body; the efficiency of the "hanging cast" was established.

4. A high incidence of carpal scaphoid fractures was encountered; good results were obtained by prolonged immobilization if instituted early.

5. Fingers immobilized in extension showed a high incidence of stiffness; positions of flexion should be used, and the uninjured fingers must not be immobilized.

6. Nerve and blood vessel injuries were frequent in compound fractures of the upper extremity, and these injuries often take precedence over treatment of the fracture.

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REHABILITATION OF THE SURGICAL PATIENT IN ARMY HOSPITALS IN WORLD WAR II

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MEDICAL CORPS, ARMY OF THE UNITED STATES

AMONG the interesting developments of surgery of the recent war and evident as of interest in prior wars was the importance of developing as part of medical treatment a planned program of convalescent reconditioning. The forgotten surgical patient in civil practice is he who has been discharged from the hospital to the home care of relatives for the convalescent period. The Surgeon General in 1943 fully appreciated the problem relative to the soldier patient, who, when discharged from the hospital must be physically fit to report for a full day's military duty or discharged to civil status fit to assume the full responsibilities of independent economic life.

Every surgeon is conscious of the deleterious effect of prolonged bed rest in his surgical patients. At the present time there is a great interest in the early ambulation of patients in civilian hospitals. Perhaps no more provocative discussion has been published in medical literature of the past half century. However, recent articles by Powers[1] and Elman[2] lead the interest of the reader forward. The current situation in civilian hospitals, where nurse shortages have forced a policy of bed scarcities and rapid turnover of patients, has compelled surgeons to shorten the period of hospital stay and to utilize approved methods of accomplishing early ambulation and reconditioning.

History bears out the fact that in each great war there has been a surge of interest in the convalescent care of military patients necessitated by the critical shortages of personnel. In fact, the salvage of manpower both military and industrial has been the motivating power in each war, perhaps never before so much so as in World War II. With a good program of convalescent reconditioning, many patients have been returned to full military duty that otherwise would only have been capable of performing limited duty; and, furthermore, large numbers have been salvaged for limited duty that otherwise would have been discharged to civil life. In the recent war 58.8 per cent[3] of the wounded were returned to military duty within the overseas theaters—an important number of military personnel too have been salvaged. The best results have been reported from the Convalescent Centers of the European Theater where 84.5 per cent of the patients were returned to duty within the theater.

Perhaps the size of the problems facing the medical department in accomplishing its mission of preserving the military strength of the Army would be more clearly demonstrated by the following tabulation:

TABLE I
BATTLE CASUALTIES[1]

Wounded	Missing	Prisoners	Killed	Total Casualties*
570,783	56,867	114,205	201,367	943,222

* Figures inclusive of June 30, 1945, only.

Two factors are responsible for these results, (1) the superior quality of surgery in Army Hospitals and in the field and (2) a well organized reconditioning program, operating within each Theater of Operations and in the Zone of Interior.

The convalescent reconditioning program in Army Service Force hospitals was originally conceived of primarily for the preservation of the fighting strength of the

* Reconditioning Consultants Division, Office of The Surgeon General, U. S. Army—on terminal leave.

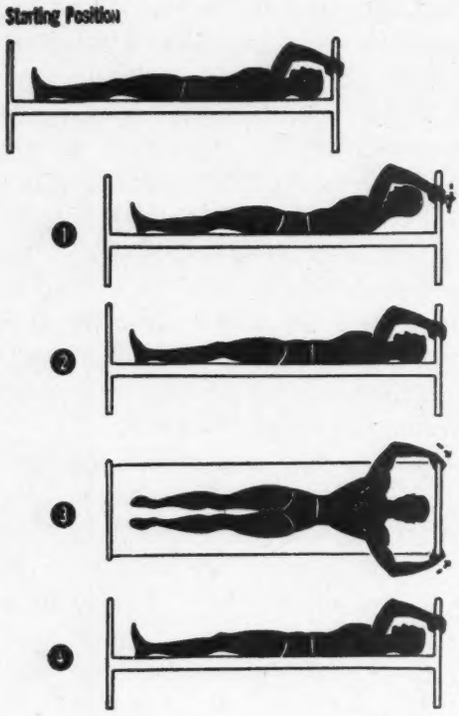
Army. It was conceived for adaptation to the surgical patient and it was developed in three aspects, (1) physical reconditioning, (2) educational reconditioning and (3) occupational therapy (operating in close cooperation with physical therapy). It seems appropriate to describe in this paper the physical reconditioning aspect primarily.

Patients were classified into four groups —each having its own program of activities adapted to the physical and mental limitations of each group, as follows: *Class* 4—bed and chair patients; *Class* 3—ward ambulant patients; *Class* 2 and 1—progressively free ambulant patients.

Even the afebrile surgical patient in leg traction profited from a physical and mental exercise program and from functional occupational therapy if those parts of his body not injured were exercised. Moreover, the program began early in convalescence. Specific exercises were developed and programs of remedial exercise and functional occupational therapy for specific muscle, joint and tendon lesions were adapted to meet individual cases in the later stages of convalescence. Each patient's program was prescribed by the ward surgeon. The patient making full recovery for return to general military duty was eventually placed on an eight-hour physical and military training program in a special section of the hospital or in barracks of a convalescent hospital. In military hospitals the number of freely ambulant cases remained large, and to confine these types of patients to ward routine too long was psychologically and physically deleterious. With a progressive physical reconditioning program, supplemented by specific remedial exercise, many serious surgical disabilities were benefited and salvaged for return to duty or prepared for return to civil life. The program was established in the bed stage of convalescence and carried through the progressive stages of recovery increasing in intensity in both its physical and mental aspects. To reproduce the entire series of exercises developed for this program is not the purpose of this paper but for those interested in more detail, reference is available in published War Department Training Manuals, TM 8-292,[5] 8-291,[6] and 8-290,[7] obtainable by inquiring at the Government Printing Office, Washington, D.C. However, it is considered of interest to produce those exercises designed for the bed patient and individually prescribed by the ward surgeon dependent upon the location of the lesion under treatment (very few bed patients could or should execute the entire series). (Figs. 1 to 6.)[14]

At the time of the peak load of patients in hospitals in the zone of interior over 25,000 patients a week were being returned from Army Hospitals reconditioned for some form of military duty. However, as the more serious battle casualties increased in numbers in the General and the Convalescent Hospitals and reached a stage of recovery considered to be stationary or resulting in permanent disability, more attention and emphasis was placed on the programs for reconditioning patients for return to civil life. This program,[8] therefore, was altered to include vocational guidance and exploratory pre-technical or pre-vocational training and less physical conditioning, while the Station and Regional Hospitals, receiving training casualties, emphasized return to military duty.[9]

Of the special programs developed for special types of seriously wounded surgical patients, three are worthy of special mention (1) amputee,[10] (2) thoracic surgery,[11] and (3) spinal cord injury.[12] Space will not permit for a detailed description but ready reference is available for those interested by making inquiry of the Office of The Surgeon General, U.S. Army, the Pentagon Building, Washington 25, D.C. These particular types of patients required special corrective exercise and training in specific conditions to become adjusted to a changed environment. The amputee training in the use of prosthesis developed special programs for upper and lower extremity cases, such as, training in the use of arm prosthesis in a telephone pay station booth and



48. CONDITIONING DRILL FOR CLASS 4. See table I.

EXERCISE 1: RAISE AND PUSH

Cadence. Slow.

Starting position. Lying on back, hands grasping the sides of the head of the bed about 8 inches above the level of the mattress.

Movement.

(1) Push down toward the floor with the hands, pushing hard enough to lift head and shoulders slightly from the bed. Do not assist this movement with the abdominal or thigh flexor muscles. Do not bend the head forward.

(2) Recover to starting position.

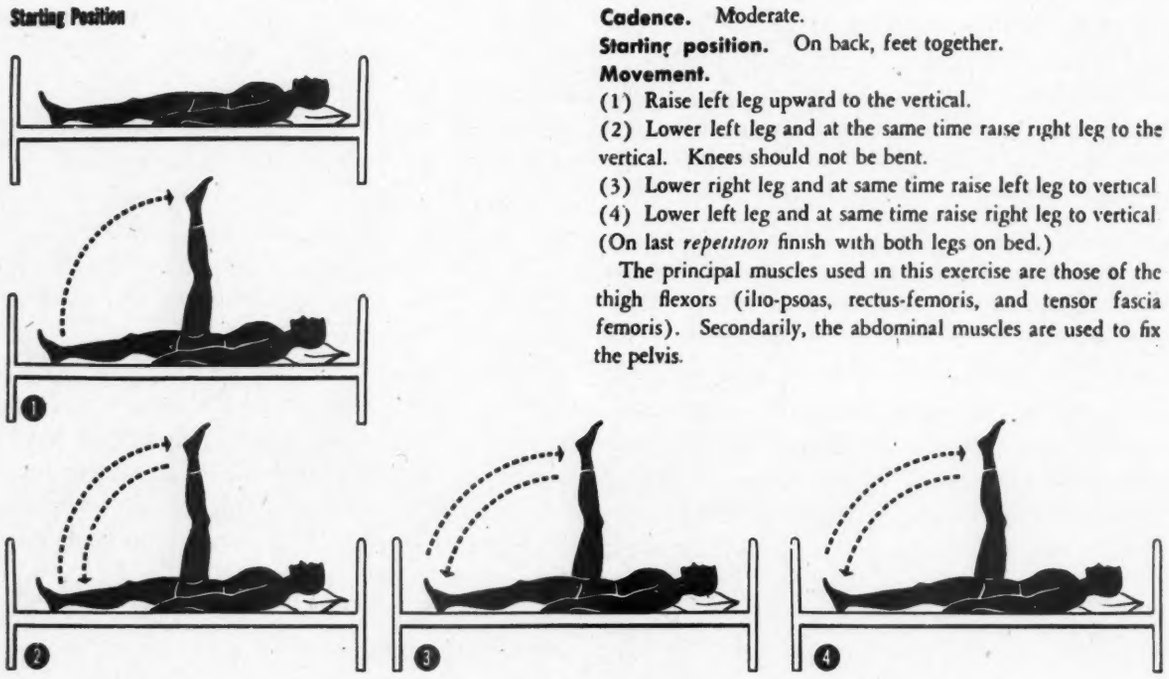
(3) Push with both hands overhead in a direction away from the feet, and at the same time pull the hands together inward toward the middle line of the bed.

(4) Recover to starting position.

The principal muscles used in this exercise are the shoulder muscles and those of the upper back which adduct the upper part of the shoulder blades (upper and middle trapezius and rhomboids). The other muscles of the arms and forearms are used secondarily.

23

EXERCISE 1A: ALTERNATE LEG RAISER



Cadence. Moderate.

Starting position. On back, feet together.

Movement.

(1) Raise left leg upward to the vertical.

(2) Lower left leg and at the same time raise right leg to the vertical. Knees should not be bent.

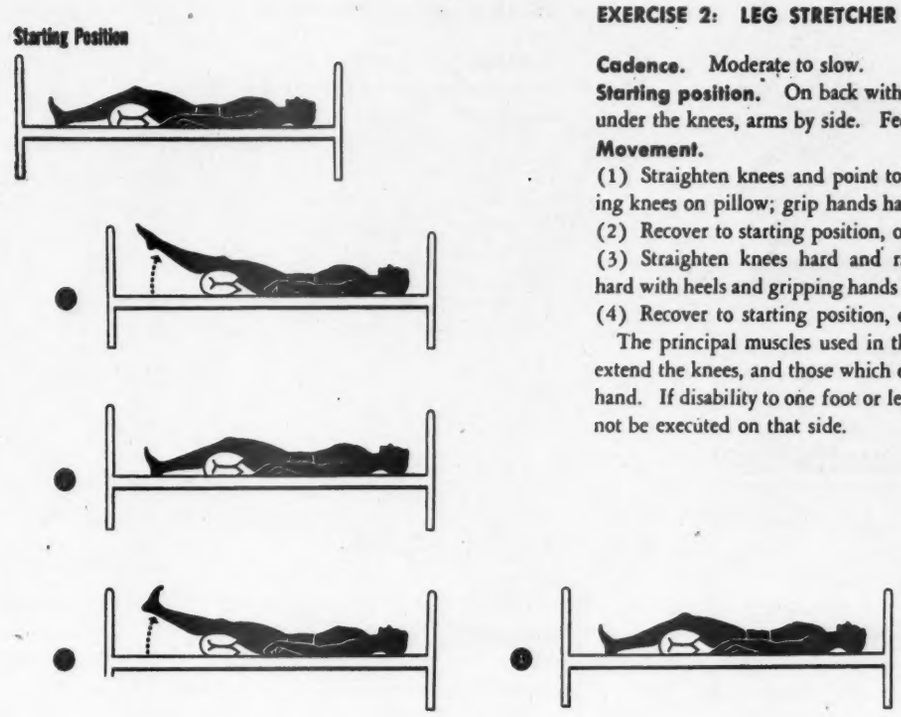
(3) Lower right leg and at same time raise left leg to vertical

(4) Lower left leg and at same time raise right leg to vertical (On last *repetition* finish with both legs on bed.)

The principal muscles used in this exercise are those of the thigh flexors (ilio-psoas, rectus-femoris, and tensor fascia femoris). Secondarily, the abdominal muscles are used to fix the pelvis.

24

FIG. 1.

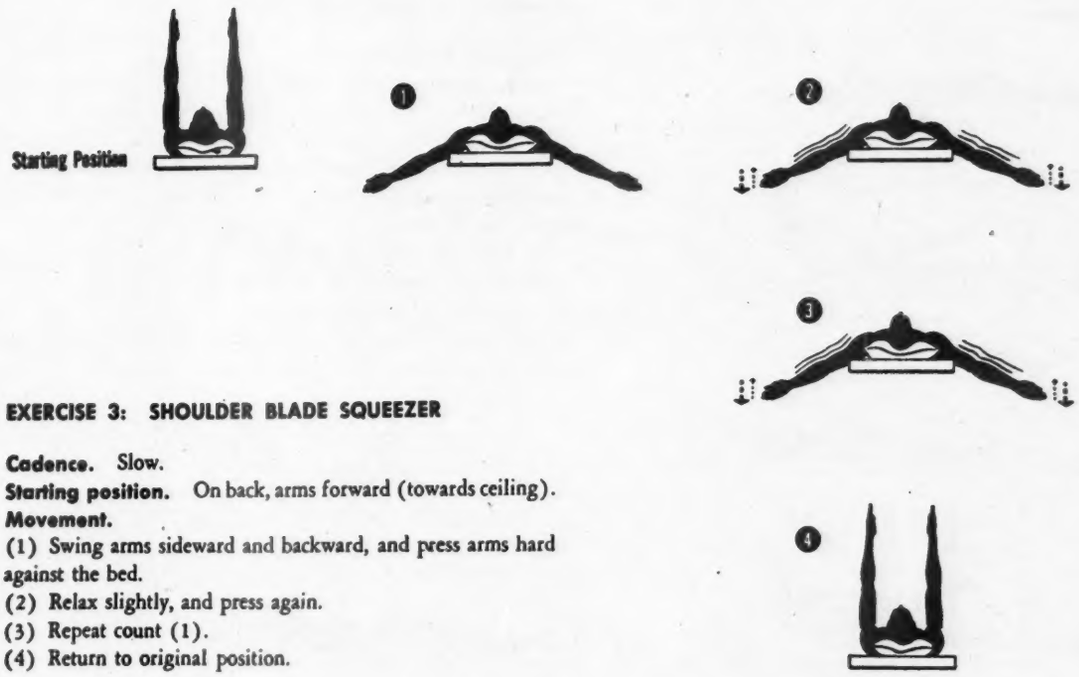


25

EXERCISE 2: LEG STRETCHER

Cadence. Moderate to slow.
Starting position. On back with pillow doubled and placed under the knees, arms by side. Feet together.
Movement.
(1) Straighten knees and point toes downward, forcibly resting knees on pillow; grip hands hard.
(2) Recover to starting position, opening hands hard.
(3) Straighten knees hard and raise toes, pushing forward hard with heels and gripping hands hard.
(4) Recover to starting position, opening hands hard.

The principal muscles used in this exercise are those which extend the knees, and those which extend and flex the foot and hand. If disability to one foot or leg exists, this exercise should not be executed on that side.

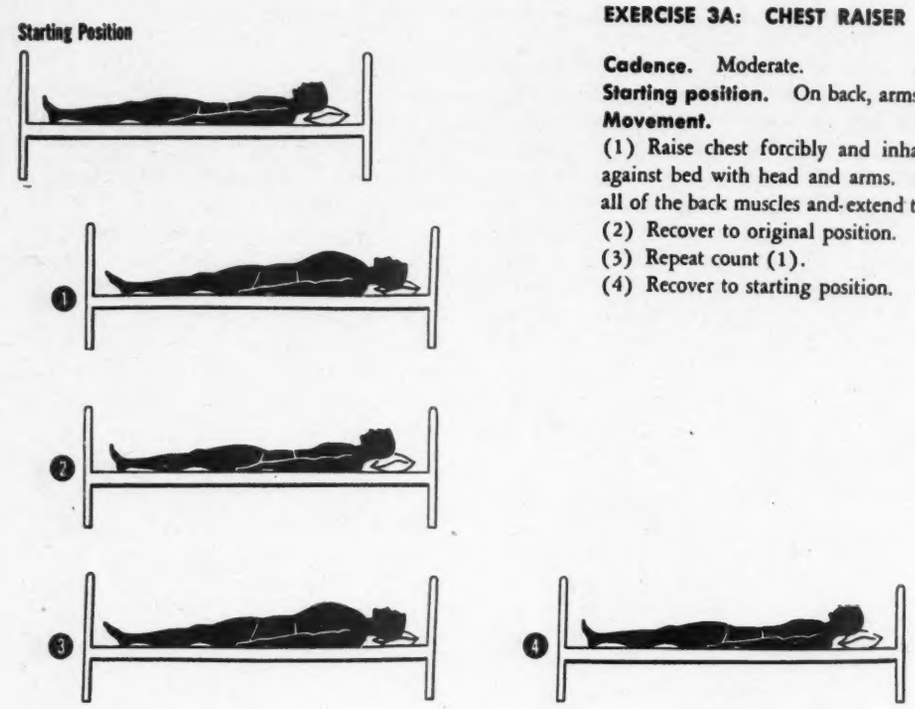


EXERCISE 3: SHOULDER BLADE SQUEEZER

Cadence. Slow.
Starting position. On back, arms forward (towards ceiling).
Movement.
(1) Swing arms sideward and backward, and press arms hard against the bed.
(2) Relax slightly, and press again.
(3) Repeat count (1).
(4) Return to original position.

26

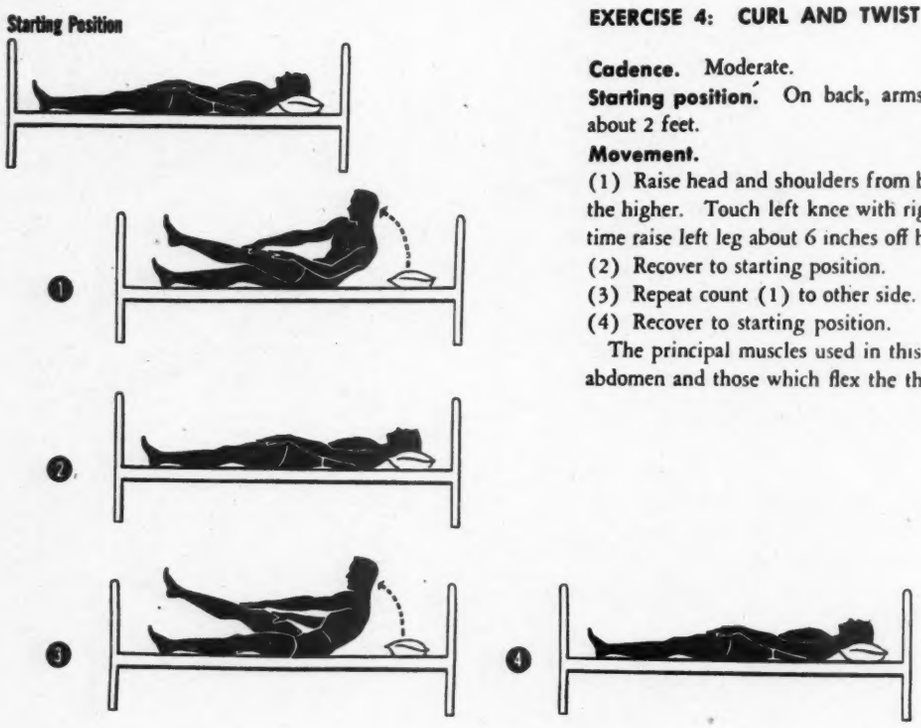
Fig. 2.



EXERCISE 3A: CHEST RAISER

Cadence. Moderate.
Starting position. On back, arms by sides.
Movement.
(1) Raise chest forcibly and inhale deeply, press backward against bed with head and arms. At the same time, contract all of the back muscles and extend toes downward hard.
(2) Recover to original position.
(3) Repeat count (1).
(4) Recover to starting position.

27



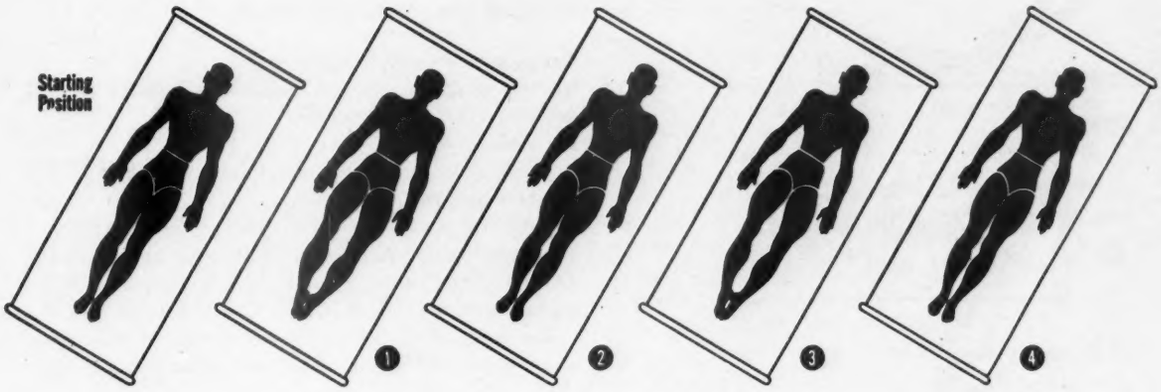
EXERCISE 4: CURL AND TWIST

Cadence. Moderate.
Starting position. On back, arms by side, feet separated about 2 feet.
Movement.
(1) Raise head and shoulders from bed, raising right shoulder the higher. Touch left knee with right hand, and at the same time raise left leg about 6 inches off bed
(2) Recover to starting position.
(3) Repeat count (1) to other side.
(4) Recover to starting position.

The principal muscles used in this exercise are those of the abdomen and those which flex the thigh.

28

FIG. 3.



EXERCISE 4A: FOOT SUPINATOR

Cadence. Slow.

Starting position. On back, arms by sides, toes pointed downward.

Movement.

(1) Bend ankles inward until soles of feet are together and knees are very slightly bent; press soles together hard.

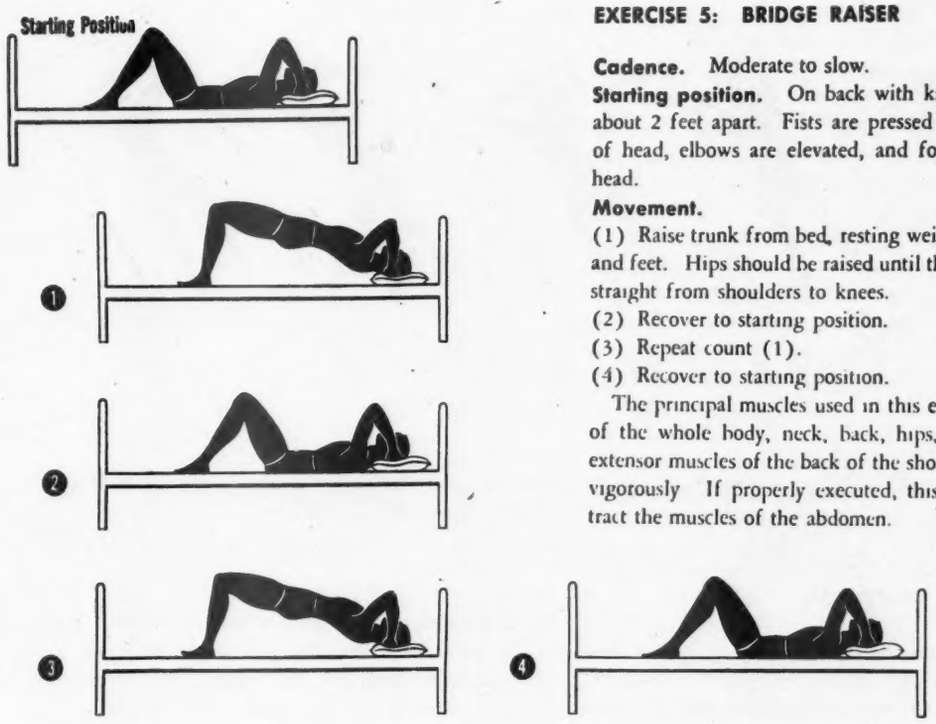
(2) Recover to starting position.

(3) Repeat count (1)

(4) Recover to starting position.

The principal muscles used in this exercise are those which supinate the feet, the muscles of the soles of the feet, and the adductors of the thighs. If the patient has undergone a recent abdominal operation, he should press his heels hard against the bed.

29



EXERCISE 5: BRIDGE RAISER

Cadence. Moderate to slow.

Starting position. On back with knees drawn up and feet about 2 feet apart. Fists are pressed on pillow at either side of head, elbows are elevated, and forearms are alongside of head.

Movement.

(1) Raise trunk from bed, resting weight solely on head, fists, and feet. Hips should be raised until the body is approximately straight from shoulders to knees.

(2) Recover to starting position.

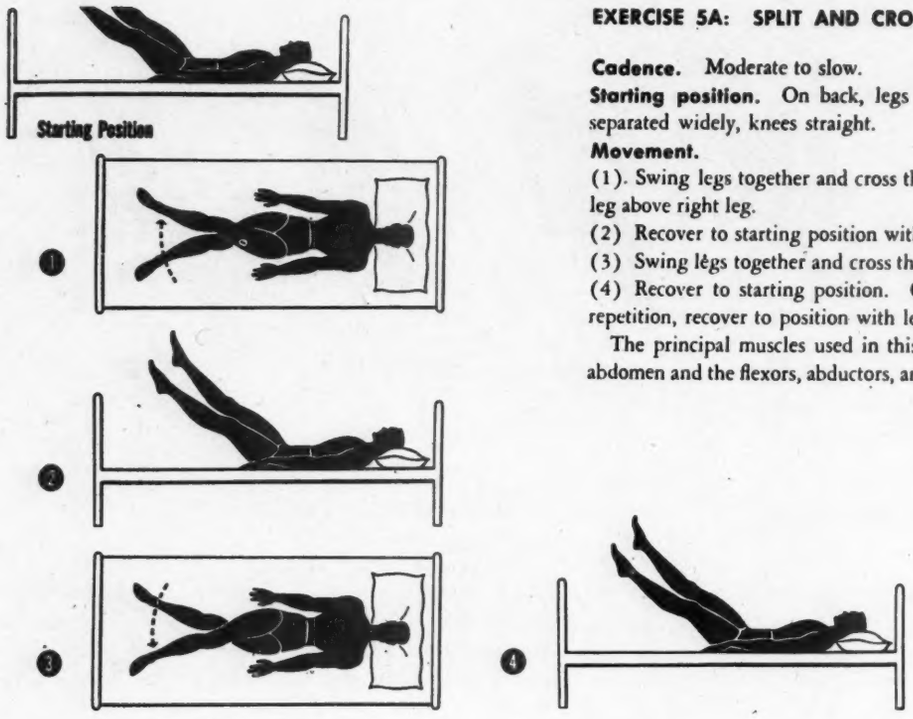
(3) Repeat count (1).

(4) Recover to starting position.

The principal muscles used in this exercise are the extensors of the whole body, neck, back, hips, and hamstrings. The extensor muscles of the back of the shoulders are also exercised vigorously If properly executed, this exercise does not contract the muscles of the abdomen.

30

FIG. 4.



EXERCISE 5A: SPLIT AND CROSS

Cadence. Moderate to slow.
Starting position. On back, legs raised from the bed and separated widely, knees straight.
Movement.
(1). Swing legs together and cross them as far as possible, left leg above right leg.
(2) Recover to starting position with legs widely separated.
(3) Swing legs together and cross them, right leg over left leg.
(4) Recover to starting position. On last movement of last repetition, recover to position with legs extended on the bed.

The principal muscles used in this exercise are those of the abdomen and the flexors, abductors, and adductors of the thighs.

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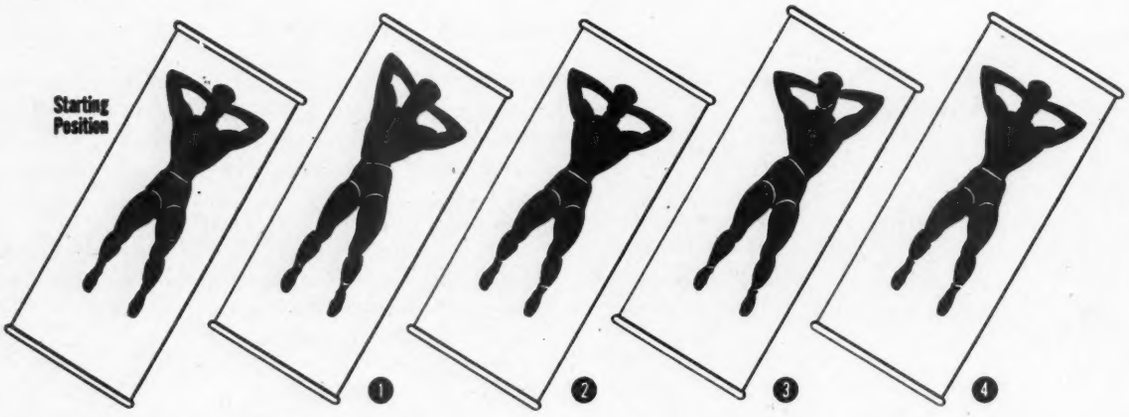

EXERCISE 6: HIP SHRUGGER

Cadence. Slow.
Starting position. On back, hands behind head, knees fully bent, and feet about 18 inches apart.
Movement.
(1) Raise left hip from the bed and "shrug" it up towards the armpit on that side as though trying to bring top of hip bone under the armpit. (The hip movement is like raising one foot from the ground while standing *with both knees straight.*)
(2) Recover to starting position.
(3) "Shrug" the right hip upwards toward the right armpit in a similar manner.
(4) Recover to starting position.

The principal muscles used in this exercise are the muscles of the sides of the abdomen (quadratus lumborum, external and internal obliques, and the erector spinae muscles on the side upon which the shrugging movement is made).

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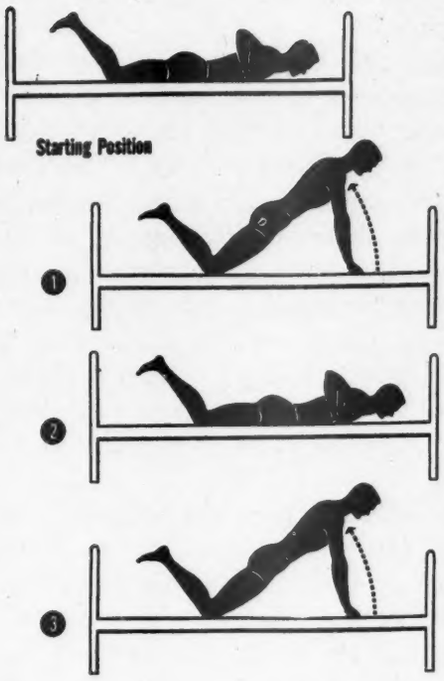
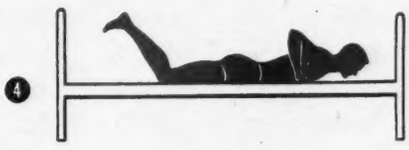
FIG. 5.



EXERCISE 6A: KNEE DIP

Cadence. Moderate to slow.
Starting position. Prone on bed; arms at thrust, with fists resting on bed on either side of chest just below the line of the shoulders; and knees flexed.
Movement.
(1) Push downward with fists, raising the body in the ordinary push-up movement, but rest on knees rather than on feet. Body is straight from shoulders to knees.
(2) Recover to starting position.
(3) Repeat count (1).
(4) Recover to starting position.

The principal muscles used in this exercise are the thigh flexors; the muscles of the abdomen; those on the backs of the arms (triceps), the anterior shoulders (anterior deltoid) and the anterior chest (pectoralis major); and those which pull the scapulae forward (serratus anterior)



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EXERCISE 7: FOUR-COUNT BREATHER

Cadence. Slow.
Starting position. On back, hands on hips
Movement.
(1–2–3–4) Inhale on four counts, taking a deeper breath on each count. Usually the patient will have inhaled fully by the third count, but he should try to inhale further on the fourth count.
(5–6–7–8) Exhale in "waves" in four counts. Try to blow all of the air out on the seventh and eighth counts.

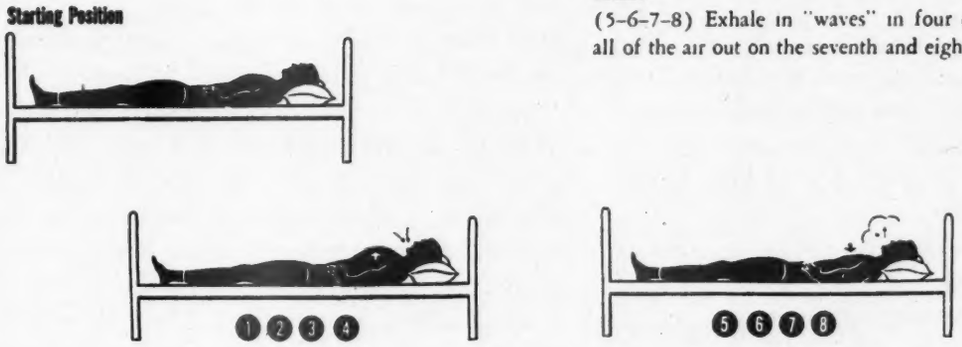

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Fig. 6.

training in the use of leg prosthesis in the steps of modern dancing. The occupational therapists developed special training equipment for the arm cases and the physical therapists for the legs. Sports and games were an active part of this program and nothing was more stimulating than to see the baseball games played between the leg and arm cases at any and all of the seven amputation centers. In the thoracic surgery program special preoperative and postoperative breathing exercises were developed, greatly improving and shortening the convalescence of such cases. The fact that wounds of the chest of World War II have resulted in a minimum of serious sequelae can partly be attributed to the development of this special program at the Thoracic Centers. However, of even greater significance was the development in the Paraplegic Centers of an active program of rehabilitation whereby the greatest majority of the patients were taught independent ambulation and even those with cord transections learned not only to walk with braces but to mount a bus step and to take care of themselves in travelling on a week-end pass or convalescent furlough. Not all such cases will progress to sufficient recovery to be discharged home, but comparing the results of the last World War paraplegics with those of this World War, to date a marked improvement has been demonstrated. Special reconditioning programs for the blind and the deaf assisted notably in fitting them for proper adjustment to civil life.

Until such time as definitive end results are published, it is impossible to fully evaluate the Army reconditioning program. Much experience has been gained in the twenty-two months that the program operated most actively and much benefit was provided to patients in Army Hospitals. At the peak load of patients in the hospitals of the continental United States over 220,000 patients were participating daily in the reconditioning program and many soldiers were being discharged to duty or to civilian life better conditioned and better informed than would otherwise have been possible.

Favorable evaluation has been placed on the importance of this reconditioning program by the Chief of Staff in his biennial report to the Secretary of War,[13] "So that no casualty is discharged from the Army until he has received full benefit of the finest hospital care this Nation can provide, the Medical Service has established a reconditioning program. Its purpose is to restore to fullest possible physical and mental health any soldier who has been wounded or fallen ill in the service of his country.

"To insure that men are properly prepared for return to civilian life the Army established 25 special convalescent centers. At these centers men receive not only highly specialized medical treatment, but have full opportunity to select any vocational training or recreational activity, or both, they may desire. Men, for example, who have been disabled by loss of arms or legs are fitted with artificial limbs and taught to use them skillfully in their former civilian occupation or any new one they may select. Extreme care is taken to insure that men suffering from mental and nervous disorders resulting from combat are not returned to civil life until they have been given every possible treatment and regained their psychological balance."

In conclusion, it may be stated that the Medical Department carried out its mission of preserving the fighting strength of the Army with the development of its reconditioning program; that special programs were developed for each stage of convalescence from bed patient to full recovery; that special programs were developed for specific seriously wounded surgical patients, notably amputee, thoracic surgery and paraplegic as well as for the blind and deaf; and that not only were 58.8 per cent of the wounded returned to duty from the hospitals within the overseas theaters but that of those wounded returned to hospitals in the continental United States from overseas, considerable numbers recovered

to resume limited duty or were returned to civilian life better conditioned for the resumption of independent economic existence.

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14. Ibid.[5] Pp. 23–37.

Sutures, combined with an anterior wire loop by the method of Martin, recommended by Campbell, make a very satisfactory reduction and fixation of a fractured patella. . . . Total excision of the patella as practiced by Brooke is not recommended as routine practice, but undoubtedly will give good results and may be used in extensive compound comminuted fractures.

From "Operations of General Surgery" by Thomas G. Orr (W. B. Saunders Company).

FRACTURES AND DISLOCATIONS OF THE SPINE IN WARFARE

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IN the history of mankind is chronicled a steady progression of means of devastation and destruction equaled only by the ingenious methods that have been devised for their prevention and repair. During the recent war, until the days of its conclusion, the application in warfare of instruments for destruction failed to gain the ascendancy. The employment of a new source of energy, previously unimagined by the uninitiate, tipped the scale so alarmingly on the side of destruction, that one questions not only whether an equalizing advance will be made, but whether such an advance will be possible.

It is assumed that such progress is possible, and it is hoped that knowledge, gained by experience, particularly that acquired in warfare, will aid, at least in small measure, in starting the balance back on its long course in the desired direction.

A notable achievement during the second world war was the capacity for action on large scale and in wide scope. It is apparent that this is true in all phases of medicine and surgery. There were greater numbers and varieties of single and combined injuries than ever before. Injuries of the spine were no exceptions. However, to attempt to present a complete report of injuries to the spine would be impossible for obvious reasons.

This résumé is a rather brief recounting of a modest experience at a Naval Mobile or Fleet Hospital on a Pacific island, and at one of the larger Naval Neurosurgical Centers.

It is desired to recount the methods of caring for casualties arriving at the Naval counterpart of the Army Base Hospital in the Zone of the Interior, the treatment during this hospitalization, evacuation to the mainland, the problems pertaining thereto, and experiences at a fully equipped and staffed Neurosurgical Center. Fractures and dislocations of the spine were so frequently associated with injuries to the spinal cord that these cases were admittedly better handled by these activities.

PROBLEM OF EVACUATION

The line of evacuation of Naval casualties, particularly from the various medical activities on the beach-heads, pointed directly to fleet or base hospitals situated on islands selected because of their geographical position on sea lanes homeward and because of their climate and relative security. With each advance toward the enemy home islands, it became necessary to transport evacuees over greater distances. This was done chiefly by surface craft, and principally by vessels of the amphibious force. In the earlier days of the campaign in the Pacific, before the arrival of the landing craft, transportation of the wounded was carried out by large Naval transports returning from the initial lands, air-transports when landing strips had been secured, and inter-island evacuation by Hospital Ship. As larger islands were secured and consolidated, air transportation assumed greater proportions and regular flights were scheduled. The availability of these various means of transportation as continuously subjected to the demands of the overall logistics for the Pacific strategy, and which repeatedly was reflected in the total number of units available for the evacuation of casualties. This obviously mitigated against any rigid plan which would regulated length of hospitalization at the various medical ac-

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tivities along the line of evacuation down through the Islands and, to some extent, evacuation to the continental United States.

It is readily observed that the problem of evacuation in this theater was somewhat unique, in that the wounded marine, sailor, or soldier, by the time he arrived at a Fleet Hospital or Naval Base Hospital, whether he had a fractured spine with a complete paraplegia, or a leg wound, had been carried through jungle mud or over coral to the nearest aid station, possibly in a Stokes stretcher to the Marine Regimental or Battalion Hospital on the Beach. From this point, he was carried to an adjacent L.S.T. for a voyage which, at times, may have been many hundreds of miles to another island where he was admitted to a Naval Base Hospital after a short trip by ambulance or jeep. Following a stay at this hospital of a week or two, depending on transportation and the need for beds, he again embarked, perhaps on a Hospital Ship, for a voyage of possibly a thousand miles to a third island, and was admitted to a Naval Mobile or Fleet Hospital. The total mileage travelled up to this point may have been perhaps two thousand miles.

Local difficulties in the European Theater were, of course, encountered and the evacuation problem was subject to similar influences, mainly weather, which closed airports and roads. However, as in the opinion of War Department Observers there is no ideal method for handling these spinal cases in the type of warfare encountered in the Pacific and European areas. It was the aim of most medical officers to evacuate as speedily as possible all spinal cases to a properly equipped Neurosurgical Center, or in the Islands, to the Larger Naval Hospitals where there would likely be a Neurosurgical team. Unfortunately, this was not always the procedure. In some instances, spinal cases were treated in the more forward areas by relatively inexperienced or overzealous officers. Occasionally, paraplegics were incompletely treated during the optimum period. Frequently, the latter was true because of transportation exigencies. However, no patient suffered because of lack of treatment. It was our practice to record the interval between the time of being wounded and first aid. There was no such interval longer than fifteen minutes, which is a tribute to the Hospital Corps.

Specifically, the over-all policy consisted of the following: In the care of spinal injuries rapid evacuation from the field, immobilized as far as possible to the aid station where a survey of the situation was made by the Medical Officer and the necessary emergency treatment started. Depending on the local situation, the patient was transferred either to the Beach Hospital directly or to a waiting L.S.T. or L.C.I. Aboard ship, or at the Beach Hospital, definitive surgical treatment may have been undertaken. Many of these cases had associated abdominal, thoracic or extremity wounds which not only necessitated immediate intervention but precluded rapid evacuation. During the voyage down the Islands the primary concern was treatment of shock, positioning of the patient, and perhaps the application of a plaster spica, the insertion of an indwelling urethral catheter and nutrition. The use of suprapubic cystotomy was somewhat unusual. The problem at sea was, of course, quite different depending upon the size of the ship, the amount of damage sustained by the vessel, etc. In this respect there were isolated cases even on large ships where the actual distance to the sick bay was not great but because of the distribution of the damage, circuitous routes through narrow passageways or small apertures became necessary. In such instances not only was some form of immobilization impossible, but in order to evacuate the patient, it became necessary to manipulate the spine disastrously so that the patient could be passed through a small aperture providing the only means of egress. Usually, however, the Medical Department of ships in combat had im-

mediately available the equipment and enlisted personnel to care for spinal cases; the patients were then evacuated either directly to a hospital ship, or transferred upon the next island stop. None of the Naval Hospitals in the area was designated as a Neurosurgical Center, therefore, the line of evacuation was more or less the same for all types of injuries.

The Naval Base Hospitals and the Mobile or Fleet Hospitals were the chief focal points at which evacuation of casualties to the mainland was decided upon and carried out. These hospitals were authorized to hospitalize patients up to a period of four months. This period was judiciously selected and proved advantageous. It allowed a sufficient period of time for definitive treatment, and equally important was the fact that during this time the patients with spinal injuries, particularly the paraplegics, could be prepared for the voyage of six thousand miles across the Pacific. A cruise of this length would ordinarily present a hazard simply by reason of total distance travelled. There was also the added difficulty of days spent in equatorial waters, below decks with perhaps no cooling system, encumbranced by a plaster jacket, tidal drainage apparatus, and the individual's knowledge or suspicion that he might never walk again, that he was going home a cripple.

On arrival at the West Coast, the spinal cases were admitted to the large Naval Hospitals where each individual situation was again evaluated and treatment instituted as indicated. However, it was the policy of the Bureau of Medicine and Surgery of the Navy to transfer all patients needing prolonged hospitalization to the Naval Hospital nearest their homes. This directive was amended in 1945, with the designation of four Continental Hospitals, two on each coast, as Neurosurgical Centers. Thereafter, spinal injuries with nervous system complications were directed to these centers.

The frequent handling and admissions to many hospitals of the Naval casualties, and of course Army Personnel in the same area, necessitated by long distances travelled, point out the application of a newer concept concerning the position of the patient with a fractured spine while being handled. It has long been the common opinion that hyperextension, or at least extension, were the positions of choice. This was, and is true of fractures of the vertebral bodies, particularly in cases of anterior body fracture. It has been observed by many that in war injuries of the spine, particularly gunshot wounds, usually it is the vertebral arch that is fractured, the body remaining intact. Hyperextension in this type of fracture will produce additional damage to the cord by projecting fragments further into the spinal canal.

This type of injury should, therefore, be anticipated early and assumed to be present, especially when neurological signs exist, and the patient is best transported in either a neutral or prone position, The indescriminate use of the position of hyperextension during handling before an accurate diagnosis is established should be abolished.

CAUSATIVE FACTORS IN SPINAL INJURIES IN WARFARE

All types of injuries produced in civilian life occur for the same reasons in wartime in addition to those incident to combat. The frequency of occurrence of the civilian type of spinal injury is increased; however, this is due primarily to the acceleration of activity. Not only do more men and women drive vehicles and fly planes, but they do so with greater speed and less care. Further, more numerous vehicles of warfare are driven and flown around and about civilian areas. The personnel for civilian traffic control is depleted. With the demand for greater production in wartime and the consequent almost total conversion of industry to war production, the incidence of civilian injuries of this type also increases.

In actual warfare there were new variations of the old types of missiles producing

spinal injuries, notably, the high-velocity bullet, the Samurai sword, incendiary bullet, aerial-bomb and torpedo. It is interesting to note that in our experience, and so far as it has been possible to determine, no shrapnel such as that used in the first World War has been used in this war. Actually, shrapnel, named for General Henry Shrapnel (1761–1842) of the British Army, is a case or shell provided with a bursting charge, filled with balls, and exploded in flight by a time fuse. The use of the term, shrapnel, as it is employed today is not to be confused with the above and would be better discontinued. It is frequently used to describe bomb, mortar and shell fragments. The two most frequent agents in the Pacific which produced injuries to the spine were mortar fragments and Japanese .25 caliber rifle bullets.

On large island bases, the most frequent etiological source was truck and jeep accidents. Aboard ship falls into the holds, explosions resulting from enemy action and falls elsewhere about the ships, particularly in foul weather, produced the greatest number of fractures and dislocations of the spine. At sea there were, occasionally, unusual instances in which severe spinal injuries were produced as a result of explosions and torpedoing. There have been instances of spinal injuries produced by the Japanese Samurai sword, employed with the intention of decapitation which, fortunately, almost invariably failed and then at the cost of the life of the wielder. This sword can penetrate steel helmets and produce compound depressed fractures of the skull. New etiological factors during the recent war were land mines, small craft such as motor-torpedo boats, and delayed action aerial bombs timed to explode below decks, injuring those above. It is of interest in respect to the latter, that a man standing erect upon an exploding deck is more likely to sustain fractures of the os calci than a fractured spine. There were no instances of bayonet or knife wounds which produced damage to the spinal cord in our series.

CARE OF SPINAL INJURIES IN THE FIELD AND AT SEA

As already indicated, the ideal attempted in the field was prompt first aid and early evacuation of spinal cases to medical activities equipped and staffed to treat this type of injury. By the early establishment of Neurosurgical Centers in the zone of the Interior, the relatively greater facility for evacuation to rear echelons by reason of shorter distances and adequate transportation, the expeditionary Army in the European Theater was commendable. The organizational plan for the management of casualties having spinal injuries provided for rapid evacuation of these cases from the Battalion Aid Stations to the closest collecting stations, thence to the nearest evacuation hospital by ambulance; at this point, neurosurgical teams were available. According to the availability of transportation and the need for hospital beds, neurosurgeons in the forward areas were directed to carry out the surgical procedures indicated, reflecting credit upon those responsible for the plan. A similar plan was not in operation in the Pacific. As already indicated, there were no such centers in that area, and spinal cases were routed down through the Islands, stopping at hospitals where there may or may not have been a neurosurgeon.

In general, there was uniformity of agreement in the outline of treatment for spinal injuries. Simple fractures without wounds or involvement of the spinal cord presented no great problems as a rule, excepting those with displacement of bone fragments which endangered the cord. These were usually recognized early and treated accordingly with immobilization or traction. Those with combined injuries, in which the cord was damaged, obviously required more complex treatment. The necessity for early, complete, surgical intervention, under proper conditions, was perhaps not so fully appreciated in general. There was rather wide agreement with the necessity for the prevention of urinary

sepsis and improvement of the general condition of the patient. The latter was not always achieved for several reasons. The prevention of hypoproteinemia, at times, failed and consequently decubitus ulcers became serious complications. It is of interest that this was observed more frequently at a Naval Neurosurgical Center in patients admitted from other Continental Medical Activities than were seen at a Naval Fleet Hospital in the Pacific. It is recognized that these patients had been wounded in action as long as a year previously. However, they had been in the United States for many months during which time there was ample opportunity to treat the old ulcers, and certainly to prevent new ones, which was the case with the group above mentioned.

In the forward areas, uncomplicated spinal injuries or such injuries without associated wounds were the exception rather than the rule. The most grave, immediate threat to the patient's life was, of course, hemorrhage, and secondly, shock. With these under control attention could be directed more earnestly toward the spinal injury, with an accurate determination of the neurological situation. This was recorded on the patient's health record. The importance of these records cannot be overemphasized for it was possible in many instances for the Medical Officer at the next station to which the patient was admitted to have had knowledge of a progression of involvement of the spinal cord at a time when surgical intervention would afford the greatest chance for recovery. Likewise, incomplete information handicapped the surgeon in the rear areas. It is recognized, however, that during the stress of combat it was not possible for the surgeon in the forward area to pass along any information regarding the patient. One Army Medical Officer in the field will long be remembered with gratitude for having written a brief but pertinent note in pencil on a strip of adhesive tape which was attached to the patient's upper chest recording important neurological observations existing shortly after injury. The level of paralysis and sensory deficit had ascended during evacuation, and knowledge of this change by reason of the adhesive tape note was valuable.

Casualties were admitted to the Naval Mobile or Fleet Hospitals usually in fairly large numbers. As many as five to seven or eight hundred in a group. With such a sudden influx of wounded, and frequently they would be Army, Navy, and Marine Corps Personnel, early availability or records was necessary. The Army patients we saw had their records in jackets pinned to their clothing in an obvious place. The Navy health records were collected together aboard ship and sent directly to the hospital record office for official "admission" of the patient to the hospital. Notes were easily made on the Army record. The Navy records were repetitious, cumbersome and not with the patient.

Fractures, dislocations, and fracture-dislocations of the vertebral column without injury to the spinal cord or cauda equina, after the initial treatment for shock, etc., were completed, were managed according to the level of injury. Only by means of careful neurological examination and detailed *x*-ray studies of the area implicated could a rational approach to reduction be made.

In the cervical region, reduction was best accomplished by the method described by Hoen[1] and the method of Crutchfield.[2] The method described by Stookey[3] was used to advantage for cooperative patients without fractures involving the posterior neural arch. Certainly patients handled in this manner are the most comfortable. The first two methods mentioned were most satisfactory for the reduction of fractures in which there was marked displacement of fragments and, in particular, for attempting reduction long after injury. In this regard, the greater security afforded by the method of Hoen in which stout wire is passed through burr holes in the skull makes it superior to the Crutchfield tongs which occasionally slip-

ped. The protagonists for the tongs will argue that they will not slip when applied correctly which is true. However, since it is the simpler method it was employed on occasion by some not quite adept in its application. With both methods, weights greater than fifty pounds have been used.

Skeletal traction was applied for periods of three to five weeks depending on the type of fracture and the particular components of the spine injured, following which a plaster spica was applied. None of our patients were evacuated in traction. Those patients in which the lower cervical spine was fractured, especially mild compression fractures of the anterior aspect of the body, were simply placed in a plaster cast and evacuated aboard the next available transport.

In the thoracic region, the same was true for the group comparable to that last mentioned. No satisfactory method for adequate reduction of marked dislocation (more than 50 per cent lateral displacement), or for situations wherein vertebral bodies are compressed to two-thirds their normal width have been forthcoming in our experience. These injuries are rare, however, without damage to the spinal cord or cauda equina. It has been observed in our series in a few instances that it is possible, in the presence of such marked lateral displacement of vertebral bodies, for the cord to remain in intact anatomical continuity. With knowledge gained in the war that return of some function is possible even when decompression is undertaken many months after the original injury, this fact contains important implications. Without such marked displacement of vertebral body fragments, and when not complicated by fractures of the laminae or pedicles, the automobile-jack method of Ryerson[4] was employed. The use of the Bradford frame, when extension was indicated, was rather unsatisfactory in that it tended to promote bed sores, so that when possible, Stookey's method was used.

The above outline of management applied also to fractures of the lower spinal column with the additional use of the method described by Watson-Jones.

Uncomplicated injuries to the sacrococcygeal region were rare, not severe, and readily amenable to the conservative measures outlined above.

Fracture, fracture-dislocation and dislocation resulting from injury sustained in combat, associated with damage to the spinal cord and cauda equina, formed by far the larger group. Of this group, cervical cord injuries occurred in 10 per cent of the cases, 23 per cent were upper thoracic cord injuries, the lower thoracic injuries comprised 34 per cent, and the cauda equina was involved in 33 per cent of the cases. These figures do not represent the overall statistics but are personal observation.

With experience, surgeons have learned that not only is the question of whether the spinal cord is intact or not of paramount importance, but how much and what can he do at the Base Hospitals or at the Neurosurgical Centers in the Zone of the Interior to minimize the disabling effects of complete anatomical interruption of the cord. Also as the result of wider experience, he has learned that the clinical criteria for complete section of the cord were surprisingly erroneous at times casting doubt upon the justification for conservatism. The multiplicity of wounds, observations that not all "complete paraplegics" conform to the classical pattern described by Riddoch,[5] the occurrence of pain below the level of section, and others, presented the World War II surgeons with perplexing problems impossible to solve immediately and obviously giving evidence of incomplete knowledge, rendering the solution more complex and difficult. The availability of the sulfa drugs and the antibiotics removed some of the restrictions upon surgery. As a result of this experience, new reasons for more radical measures were added to the prevailing list of indications for surgery as outlined by Mixter,[6] Wortis and Sharp,[7] Browder and Grimes[8]

and others. In addition, the surgeon had come to realize that rehabilitation should begin for the wounded man soon after injury and that the rôle of the surgeon in the forward area could be one which might determine an adequate adjustment of the patient to his disability. By the judicious maintenance of hope for some recovery when indicated and the assurance of a useful comfortable existence without economic burden to others in complete paralyses, more lives are salvaged.

The management of injuries of the spine with associated damage to the cord and cauda equina has been conditioned by knowledge gained in overseas and Continental U. S. Hospitals which has altered, to some extent, the indications for surgical intervention in these cases. Careful observation and wider experience have tended toward a somewhat less conservative attitude than existed prior to the onset of the war.

The following outline of the indications for surgery does not include the conditions thought to have necessitated surgical intervention at all times during the war, but includes those indications added as the result of later experiences.

INDICATIONS FOR EARLY SURGICAL EXPLORATION IN WAR CASUALTIES

Incomplete or Complete Cord Lesions in Which There Is Progression of Cord Dysfunction. This situation was considered to be as urgent an emergency as hemorrhage from an important blood vessel.

Involvement of the elements forming the posterior portion of the neural arch compressing the cord, or in danger of compressing it, if adequate reduction of the displaced fragments cannot be achieved and maintained closure and repair of the dura when penetrated by bone fragments were indications for surgery.

Fracture, fracture-dislocation and dislocation, and foreign bodies such as bomb fragments, etc., at the "critical level" of the spinal axis (from the sixth cervical segment of the cord to the first thoracic segment inclusive)! Between these two segments 80 per cent of the fibers forming the brachial plexus emerge. Loss of function of the brachial plexus renders the patient a practically helpless invalid. Preservation of about 60 per cent of the brachial plexus enables a man to walk with crutches and, with care, to be eventually useful to himself and others. A great responsibility is placed upon the surgeon in deciding upon definitive treatment or no surgical exploration when called upon to treat injuries at this level. It is our opinion that certainly those patients in whom there is a partial paralysis and encroachment upon the canal should be explored immediately, as well as those with a complete paralysis when seen early. Those with a complete paraplegia, with definite roentgeonological evidence of compression of the cord, or manometric block, should also be explored. Nicety of judgment is necessary when the *x*-ray evidence is not conclusive or the hydrodynamic examination carefully performed reveals only a partial block of mild degree. However, so much is at stake for the patient and so much is to be gained, that one must not be too conservative when confronted with this situation.

Removal of Foreign Bodies. The metallic fragments are sterile on entrance into the body. They should be removed when producing pain, if greater damage will not be done during their removal, when they have penetrated the dura, and there is a spinal fluid fistula through the portal of entry. Special attention has been directed by Lt. Col. J. L. Pool, A.U.S., to the consideration of penetrating wounds of the abdomen in which fragments lodge in the spinal canal and their likelihood of having perforated an abdominal viscus and of passing through the leptomeninges is emphasized. Flat surfaced, metallic fragments lying not entirely within the cord have been removed when the long axis of the fragment lies parallel to the long axis of the cord. The presenting portion of the fragment can be grasped with forceps and delivered along the plane of its entry after

space for its accommodation has been prepared by rongeuring enough bone laterally.

Following gunshot and other penetrating wounds received in combat, closure of the dura for persistent cerebrospinal fluid fistula is indicated. The presence of a fecal fistula communicating with the meninges demands immediate attention.

Surgery for the relief of pain was rarely necessary in the early cases. Rhizotomy may occasionally be required, rarer still, cordotomy in the cases observed during the earlier weeks.

Two factors of importance were given some consideration. These were, first, the question of lumbar puncture. Not all spinal injury cases need lumbar puncture and the danger incident to manipulating the patients for this procedure realized. However, since most of these injuries involved the laminae and since the prone position was the one usually of choice for evacuation, more lumbar punctures were attempted in the prone position.

It was realized that the greatest damage to the cord was due to hemorrhage within the cord. When found and accessible, its removal was attempted from the midline.

One additional surgical procedure carried out in the European Theater which was infrequently performed elsewhere was suprapubic cystotomy in the paraplegics. It is agreed by most that the best method of caring for the paralyzed bladder is tidal drainage. With the large number of casualties in the European campaign and an insufficient number of trained enlisted personnel to care for the complex mechanism, the method of suprapubic cystotomy was justified and adequate.

MANAGEMENT OF SPINAL INJURIES IN THE UNITED STATES

Statistics following World War I regarding spinal cord injury revealed a mortality of over 90 per cent. Not in that war, nor in civilian life since then, until World War II has this type of injury been considered a special problem. They had been accepted as hopeless cripples, and as a result of urinary sepsis and its sequelae, their early demise anticipated. The outlook for these casualties is no longer grim for all of them. Many can live out their normal expectancy of life, free from infection, and gain a livelihood. This was the goal of the Medical Departments of both Services and, although the final evaluation of their efforts is not at present available, much has been achieved toward that goal.

On evacuation to the United States, 80 per cent of the spinal cord injury cases had decubitus ulcers in addition to their paralyses, many were undernourished, and in some cases were in marked hypoproteinemia. The next most important complication to the patient after the paralysis was pain. They were worried men, eager that anything be done in order that they might walk again. The transition from the above picture to the hopeful, gratifying one outlined at the beginning of this section, was the result of teamwork among many neurosurgeons, urologists, orthopedic surgeons, internists, plastic surgeons, physical therapists, nurses and rehabilitation officers who, by their combined efforts, are demonstrating that approximately 50 per cent of all types of cervical cord injuries are walking and that between 60 to 65 per cent of all types of upper thoracic cord injuries are walking. Almost 75 per cent of the lower thoracic injury group are walking and as well as 90 per cent of the cauda equina injuries. It is true that most are ambulant with the aid of braces and crutches, either singly or combined, but it is indeed not rare that a soldier, sailor, or marine with a high thoracic lesion and a complete paraplegia, on discharge from a Service Hospital, drive off in his car to take a job.

The problem of management of casualties of this type begins immediately upon admission and individual cases re-evaluated. The malnutrition is eliminated by high protein diet, parenteral administration of amino acids, etc., whole blood transfusions when indicated, and vitamin therapy. The importance of returning normal nitrogen equilibrium is well recognized at

the centers, not only for adequate nutrition but also for the healing of wounds and decubiti. As soon as possible, when the patient's general health permits, he is measured for braces and started on exercises in bed before attempting ambulation. Meanwhile, if there has been a suprapubic cystotomy, this is closed and the patient started on tidal drainage and urinary problems are resolved so far as possible. The ideal, indicated by Munro, that an intelligent, cooperative patient who has sustained a spinal cord or cauda equina injury has a right to expect infallible twenty-four hour control of urination by the time he leaves the doctor's care, is attempted but the method of this achievement, especially when complicated, is beyond the scope of this outline.

The exercises performed in bed, in the wheel-chair or on a mat prepare the patient for ambulation and care of himself. The régime described by Deaver[9] has been of value. When there has been adequate preparation of the five muscle groups necessary for manipulation of crutches and braces are found satisfactory, the patient is initiated into the mechanism of tripod-walking with crutches or when there is preservation, particularly of the iliopsoas, the "walk-through" technic is taught. The muscle groups necessary for standing up and walking with crutches are as follows, as enumerated by Deaver, in the order of importance:

"1. Arm flexors to move crutches forward.

2. Extensors of the forearms to hold elbows stiff so they do not buckle when body weight is lifted from the floor.

3. Finger and thumb flexors to preserve grasping the crutches.

4. Dorsiflexors of the wrist to keep the hands in correct position on the hand pieces.

5. Shoulder girdle depressors and downward rotators to support the body by means of the crutches when it leaves the floor.

As already mentioned, complete sections of the cervical spinal cord preclude the possibility of walking on crutches because the nerve supply of these groups emerge from the cervical cord. Long, bilateral braces are necessary for paraplegics to stand or walk on crutches. Exercises in bed, in a wheel-chair, the gymnasium mat, and parallel bars are designed to develop those muscles of the above group which are preserved. Once the patient is capable of ambulation on the flat floor surface he is taught the technic of climbing a ramp and stairs."

Reconstructive surgery in the Centers is directed toward the greater return of cord function, the relief of pain, spasticity and contractures. Many very late laminectomies have been performed in the presence of partial lesions and block with surprisingly gratifying results. Operations for the relief of spasticity include the following: anterior root resection, obturator neurectomy, tibial neurectomy, tibial nerve section and neurorrhaphy, tenotomy and alcohol injection of the spinal cord. Operations for relief of pain include posterior root section, cordotomy, sympathetic ganglioramisectomy, cordectomy (at level of lesion), peripheral nerve section and alcohol injections.

CONCLUSION

Much credit has been given to the various specialists engaged in treating patients with spinal fractures and dislocations and their achievements during the recent war. Little mention has been made of the patients themselves. Universally, the morale was highest among these severely injured men. Their youth and general health prior to combat, together with an indomitable will to recover and be useful citizens, contributed to the success of their treatment in equal measure.

SUMMARY

A general outline of the management of fractures and dislocations of the spine in warfare is presented, based only on per-

sonal experience and observations of others engaged in similar work and not intended to represent a complete picture of the problem.

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Spina bifida may be hidden (spina bifida acculta) or obvious, innocuous or part of a widespread deformity incompatible with life. Together with its related diseases it is most common in the lumbosacral region, next common in the cervical vertebrae, and least common in the thoracic spines.

From "Surgical Treatment of the Nervous System" edited by Frederic W. Bancroft and Cobb Pilcher (J. B. Lippincott Company).

ACUTE WAR WOUNDS OF THE SPINAL CORD

ANALYSIS OF 184 CASES

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THE treatment of injury of the spinal cord has been characterized by conservatism. Closed spinal cord injuries rarely call for surgical intervention.[1] The many advances in surgical adjuncts have been helpful. Crutchfield skull traction tongs are used to great advantage in the treatment of cervical spine injuries. Hyperextension is useful in the treatment of closed dorsolumbar fractures compromising the cord and frequently allows surgery to be avoided. Munro's contribution is no where exceeded by the development of his tidal drainage apparatus for the treatment and control of the neurogenic bladder.[2] His analysis of spinal cord injuries and their treatment, and his excellent results in rehabilitation of the patient with a transected cord, have contributed much to our knowledge.[3] The trend, however, in the treatment of acute closed spinal cord injuries has been toward the conservative and only rarely has laminectomy been considered of value.[4]

Cushing, in his report as Senior Consultant of Neurological Surgery during the last war, discussed spinal cord wounds only to lament their almost invariable pitiable result and early death.[5] As a consequence of this extremely conservative attitude the problem was dealt with hesitantly in the early days of the present war. A pessimistic attitude was assumed during the author's African and Sicilian experience. Very stringent indications for operation voluntarily governed the various neurologic surgeons functioning in that theater. As a result, the usual operation following a spine wound was merely a débridement. *X*-ray evidence was relied upon to a great degree, denoting transection or sparing of the cord by the missile's passage through the neural canal. A progressive neurologic lesion would occasion operation, but those patients exhibiting such a lesion were few. It was assumed that spinal cord damage was irreversible and much was made of the rapidity of onset of the paralysis. No one of us was ever satisfied with the defeatist attitude prevalent as to the prognosis of cord wounds. Yet, in the light of previous experience of such men as Cushing, and the results of surgery in hardly comparable closed cord injuries, it seemed foolhardy to laminectomize more of those patients.

Only three laminectomies for trauma were performed by the author in the Mediterranean theater, although twenty-six such patients were observed. One patient had a progressive cauda equina lesion with a bullet in the neural canal. The other had an incomplete lesion, slowly progressive, and a spinal fluid block with *x*-ray evidence of an incomplete, unilateral, laminal fracture. These two patients obviously needed urgent surgery. There were many others whose need was not then so obvious, but who now would be operated upon unhesitatingly. Radiculitis, caused by facet and laminal fractures, was treated conservatively. All clinically complete lesions were sent back with only a tissue débridement.

All in all, the dictums of civilian experience, in so far as pertaining to laminectomy in wounds of or near the spinal cord, were unsatisfactory to the surgeon's mind and conscience. The depressing effect of finding at operation a transected or softened cord was persistent. Yet, it was accepted knowledge that if any improvement was to be

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expected, direct pressure of bone, débris and foreign bodies must be removed early, preferably under forty-eight hours. The cauda equina, if involved, must be untangled. Spinal fluid fistulas must be closed. There is no natural reparative process which will replace surgery in such conditions.

These same thoughts and dissatisfactions were being shared in the Zone of the Interior. Although assurance was not such that a general statement could be made, Colonel R. Glen Spurling at Walter Reed General Hospital,[6] and other qualified men at other centers, were operating upon these unfortunates at a later date. The results seemed encouraging to them.

These thoughts occupied our mind as we prepared for the invasion of Normandy. The first few days were so hectic that spinal cord wounds were flown back to England without operation but with suitable fixation and hyperextension. The situation was so stabilized, however, by D 5-6, that laminectomy, under fair conditions, was feasible. The author, accordingly, began to laminectomize all spinal wounds with incomplete or progressive cord lesions, and eventually all those in whom he suspected the cord to be spared. These included those patients with a clinically complete lesion, with a block of spinal fluid by Queckenstedt test, and with the *x*-rays not indicating that the neural canal had been traversed. As consultant in Neurologic Surgery for the American First Army, he encouraged qualified men to perform laminectomies in such cases. It is too early to evaluate the eventual outcome of such decompressive surgery. It was learned, however, that almost all such cords were anatomically intact although physiologically they did not conduct impulses. This seemed encouraging and the scope of laminectomy was gradually increased. More and more anatomically intact cords were found in patients in whom all clinical and roentgenographic evidence seemed to indicate a complete transection.

It is realized that return of physiologic function need not follow the mere anatomic sparing of the cord. Conversely, it is true that physiology cannot be resumed where anatomical continuity does not exist. As a primary step in the recovery of the patient, continuity must be ascertained or re-established. This can be accomplished only by laminectomy, just as such surgery can be justified only by an eventual return of function.

The most suitable place in the chain of evacuation for laminectomy is the first place wherein adequate talent and reasonable facilities for surgery co-exist. Since the need is urgent, the most suitable station is the Evacuation hospital. While nursing facilities are strained, the reward of being able to operate early upon a combined chest or abdomen-cord wound seems to justify the task. Otherwise those unfortunates will not be operated upon until their chest or abdominal wound allows evacuation, namely, from five to twelve days. Early surgery should cause less, rather than more, skin or bladder problems since reparation is frequently dramatic. Beds are not held for long periods of time because a laminectomized patient can be evacuated in three to four days if necessary.

SIGNS AND SYMPTOMS

The patient will speak of his inability, or partial inability to use his extremities, his lack of bladder control and his sensory loss. He may speak of an "electric shock" upon being struck, followed by immediate or progressive paralysis. The paralysis, however, may not be noticed in the mental haze of fighting, being wounded, and resultant shock. Rarely is the story of gradual onset of paralysis elicited and then its reliability is to be questioned. Three patients claimed a gradual onset of paralysis and all three had severed cords at operation. Patients suffering a concussion of the cord due to passage of a missile close to the cord, so-called "supersonic concussion," portray a paralysis which may be improving upon admission to the

Evacuation hospital. With no evidence of fracture, surgery is not indicated in these cases. It is indicated if bone distortion is present, since regression may occur to a point less than perfect, unless minimal bone pressure is relieved.

The patient usually is in a state of spinal shock, which persists for two or three weeks. The paralysis is flaccid and complete. Sensory loss is complete in all modalities. All reflexes are absent and the bladder is flaccid with urinary retention. Priapism is rare except in cervical cord lesions, complete or incomplete. Simple turgescence is seen frequently in cervicodorsal lesions, occasionally lumbar. It, too, has little prognostic significance.

It was found that considerable confusion existed in the use of the term, "spinal shock." It is actually a neurophysiologic process with symptoms as described above, following transection, anatomic or physiologic, of the cord. It is later converted into the picture of spastic flexion, mass reflexes such as flexor spasms and usually a spastic automatic bladder. The term was confused, justifiably, with the state of neurogenic shock, seen following cord injuries. This latter syndrome is portrayed as a persistent low blood pressure, 70-90/0-40, normal or slightly increased pulse rate, ashen color, lethargy, cold skin but normal hematocrit and blood count. Such a picture was to be expected at the level of C-7 or D-1, because of the ciliospinal group of cells and the proximity of the stellate ganglion. It was attributed in other locations to the blood loss and consequent vascular shock, due to the concomitant wound. This view was, of necessity, discarded. There is no air hunger, restlessness or distorted hemotocrit and whole blood in quantities does not alter the picture. Rather a gradual return to normal is seen, extending over a period of two or three days or even longer, regardless of treatment.

Ileus was a very common, persistent and annoying finding and was controlled only by a Miller-Abbott tube, suction, and laminectomy. Prostigmine helped in the re-establishment of tone in the gut wall but the response to surgery was more dramatic. The presence or absence of ileus was of little prognostic value. It occurred impartially in severed or intact cords, but when it was present, it occurred in physiologic severed cords. It was not seen in a clinically incomplete lesion. Type of breathing exemplified only the level of the lesion and aided in prognosis as to life. Cervical cord lesions below C-4 allowed only diaphragmatic breathing. Those patients in this series all died. Lower lesions, allowing only a small amount of costal expansion, caused pulmonary complications and, sometimes, early exodus.

One prognostic sign of some import was noted. A clinical level of anesthesia and paralysis would ascend, probably due to ischemia and softening, to two or three segments above the bony level indicated in *x*-ray. This sign usually indicated a completely transected cord. Again, however, it was not infallible.

Radicular pain was seen most frequently in incomplete lesions and constituted an indication for surgery. This pain could be extreme and uncontrollable, particularly common in cervical or cauda equina wounds.

Sensory loss is dependent upon the tracts severed or compressed. The lateral spinothalamic tract carrying pain and temperature impulses and the ventral spinothalamic tracts carrying light touch impulses are the most important. Propioceptive sensation, carried in the posterior columns, may be lost directly. All the variants of a true Browne-Sequard syndrome have been seen, the text book picture, rarely. However, a partial lesion of the cord, may, if spinal shock is not complete, allow light touch to be preserved. This is because of the gradual crossing of the ventral spinothalamic tracts. Such an instance, of course, is an indication for laminectomy. Prognostically, sensory retention is more important than motor loss. The pyramidal tracts are apparently the most susceptible to trauma. Complete motor loss is the rule

whereas some retention of light touch is commonly seen in incomplete cord lesions.

The sensory loss of pain and temperature may be confirmed by the lowering of skin temperature, loss of perspiration and the peculiar dry, flaky feeling of the denervated skin. These characteristics are discovered by drawing the fingertips lightly over the body surface. There is also a minimal, mottled discoloration of the anesthetic skin.

Associated thoraco-abdominal cord wounds are very common. This necessitates delay in surgery for the cord wound, since the thoracic or abdominal wound takes priority over the cord wound. Physiologic respiratory factors, in such cases, demand local anesthesia for the laminectomy. It is desirable also to accomplish the spinal cord surgery within forty-eight hours after the time of injury. If this cannot be done without endangering the patient, it is believed that the next most favorable time period is under ten days and that the prognostic difference between forty-eight hours and ten days is of minimal significance. The opportunity to accomplish the most for the patient with a cord wound is under forty-eight hours.

INDICATIONS FOR SURGERY

The indications for laminectomy were in a state of flux. Their scope was gradually extended to include actually any patient in whom there was a reasonable doubt that the cord had been severed. Lack of the gift of lucid expression clouds the exact pictorial description of this suspicion. Surgery cannot restore anatomical continuity where the spinal cord has been severed. It can, however, permit restoration of physiologic continuity if the cord is intact and only compressed by bone or foreign bodies. Despite common and loose descriptions of compression of the cord by blood clots, this phenomenon was never seen.

Tissue débridement is indicated in all wounds of or near the vertebral column or spinal cord. Devitalized tissue, débris, foreign bodies and accessible, removable bone fragments should be excised. Positive evidence of transection of the cord would allow one to do only this, to close any spinal fluid fistulas by means of a fascial graft and to close the muscle and skin tightly. Except for the closure of muscle and skin, this is no more than is done to any war wound. The necessity of a tight dural closure, plus local instillation of sulfonamide and penicillin powder, is obvious. Fractured spinous processes are commonly removed in such instances. Rarely, if ever, is it necessary to remove a fractured transverse process. Fascia of the paravertebral muscles is readily available for dural grafts to close spinal fluid fistulas.

Laminectomy. Obviously, any incomplete or progressive neurologic cord lesion, associated with a wound of, or near, the spinal cord, requires laminectomy. This is a self-evident truth and is universally accepted. The only exception to this rule would be an improving neurologic picture with no *x*-ray evidence of bone damage. This type of supersonic concussion of the cord is not helped by surgery, and improvement is usually spontaneous and rapid. However, an improving neurologic picture associated with laminal damage should still demand laminectomy. A return to less than normal may be replaced by complete recovery if minimal bony compression is removed. This is an important dictum.

A complete physiologic lesion demands surgery if there is any suspicion that the spinal cord is intact. Experience dictates that the cord is anatomically intact in a high percentage of such lesions. Yet, to operate each one would subject the patient to unnecessary major surgery and waste needed time. A number of factors operate to formulate the suspicion that a cord may be spared. It is not believed that any one of them, or any combination thereof, will allow one to state definitely that a cord is or is not transected.

Neurologic examination can reveal only the degree of completeness of the lesion. It

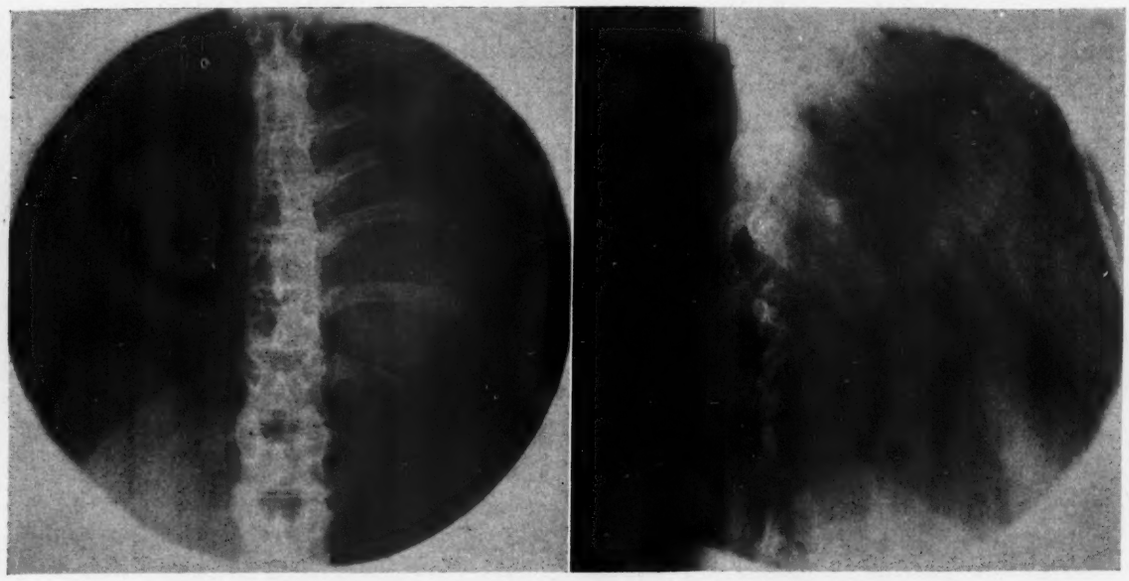

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FIG. 1. Minimal *x*-ray evidence of damage at D7-8-9-10. Operation revealed complete destruction of cord at that level.

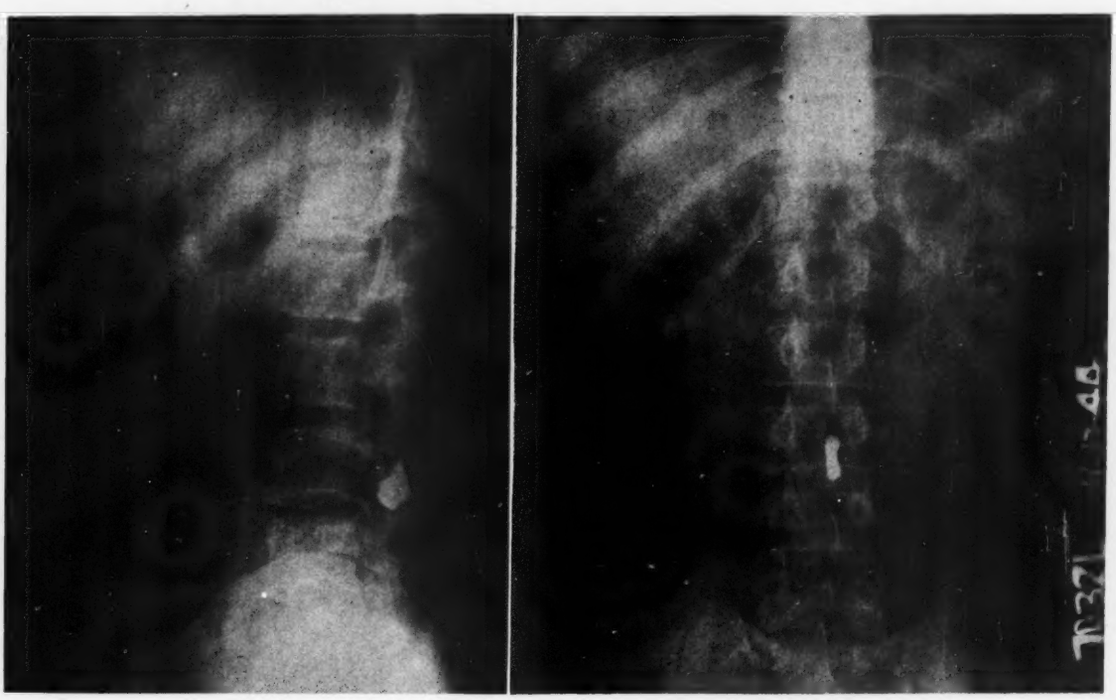

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FIG. 2. This missile crossed the neural canal and should have transected the cauda equina. Yet, at operation, the cauda was intact.

is of no help if the lesion is clinically complete.

The various stigmas described above, such as ileus, priapism and an ascending level of anesthesia are only contributory factors in arriving at a decision. No one is reliable as to sparing or transection of the spinal cord.

Roentgenographic evidence in the field without a moving Bucky diaphragm does not present criteria for acceptance or rejection of a patient for laminectomy. It is, however, the most reliable of all the above indications. The amount of laminal damage is difficult to evaluate by *x*-ray. The obvious ones are no problem, but a very

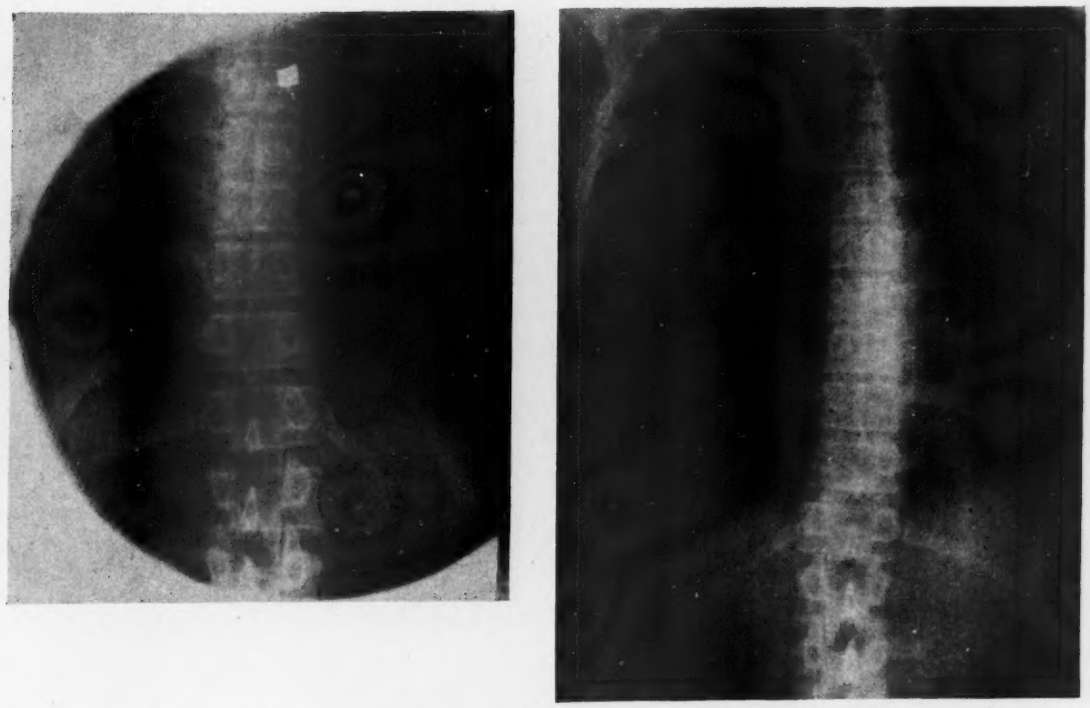

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FIG. 3. A and B, pre- and postoperative *x*-ray of missile at D7. Hemi-laminectomy is difficult to see in *x*-ray.

minimal amount of damage by *x*-ray may be revealed at operation as gross damage with cord transection. (Fig. 1.) Conversely, apparent crossing of the neural canal by a large fragment with marked bony damage, may be revealed as a lesion sparing the cord. (Fig. 2.) Facet deformities are even more difficult to recognize because of technical drawbacks inherent in field equipment.

The Queckenstedt test to determine the presence or absence of a spinal fluid block, actually is of little value in estimating suitability for operation. A negative Queckenstedt may be found in a partial cord lesion, the very case needing urgent operation. Conversely, almost every complete transection of the cord will reveal a block of cerebrospinal fluid by Queckenstedt because of the local tissue damage and débris. To rely on such a test for this purpose is foolhardy because it tells us nothing. For teaching purposes, to assert that every block should be relieved is acceptable, but many transected cords will be found. To reject every negative test is to miss the patients one may help the most. A minimal lesion after all recovers the fastest and most completely.

Consequently, a collective and judicious survey of all these unreliable factors must be made to determine operability. Experience is the greatest attribute and such experience is rare and hardly found since comparable civilian wounds are few. Error on the side of superfluous surgery is to be preferred to error on the side of conservatism. It would be better, if only more humane, to operate many hopeless patients to save one. Irrefutable evidence of cord transection, however, should obviate unnecessary surgery. The burden of proof lies on the side of determining a transected cord. The cord should be assumed spared until it is proved to be transected.

Hemi-laminectomy has come to fill a very useful rôle in war surgery. (Fig. 3.) Unilateral severe radiculitis, due to traumatic distortion of facets and intervertebral foramina, may be relieved by this procedure. Removal of foreign bodies from the neural canal is expedited. Unilateral cord compression by fractured lamina can be easily relieved. It is a particularly useful

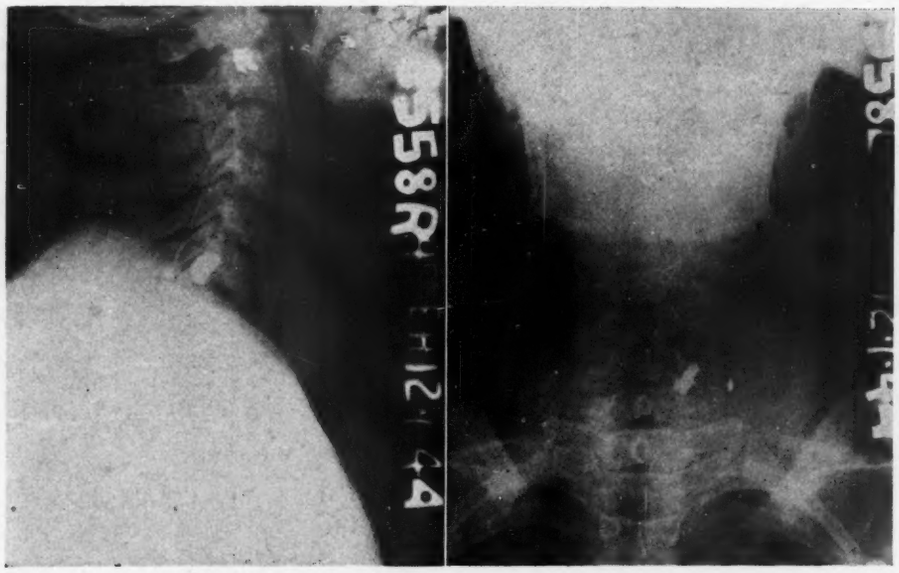

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FIG. 4. Unilateral cord compression at C6 relieved by hemi-laminectomy.

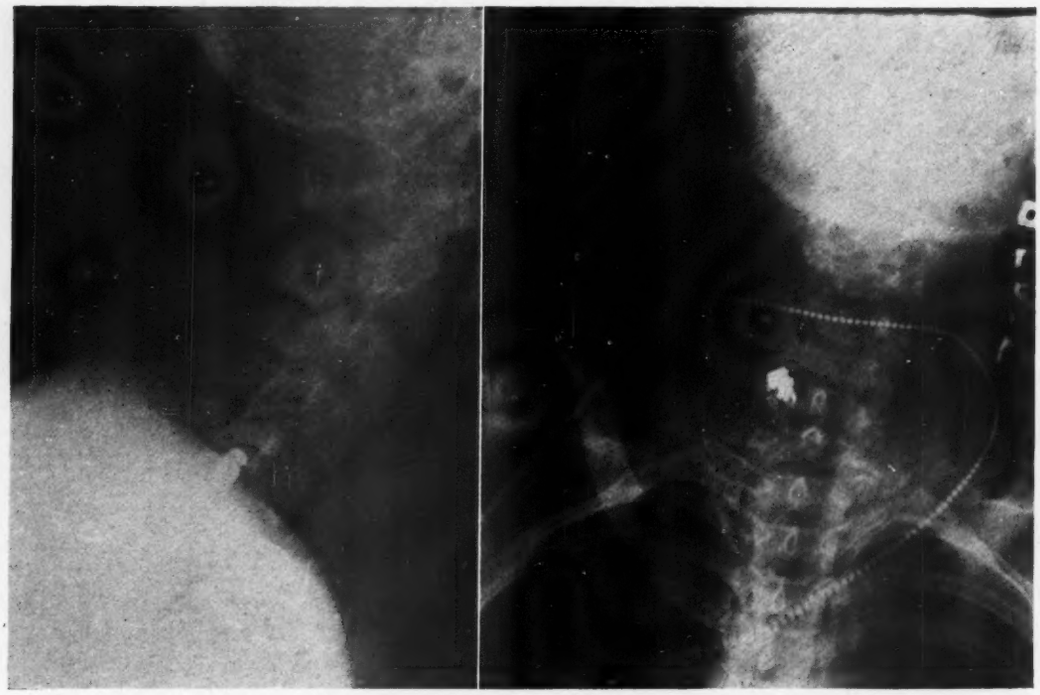

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FIG. 5. Unilateral cord compression at C5-6-7 relieved by hemi-laminectomy.

procedure in the cervical region. (Figs. 4 and 5.) Indeed, it seems to be the only necessary procedure since all the patients requiring a wide laminectomy died. The reason obviously is that any foreign body crossing the neural canal in the cervical region will occasion death. (Fig. 6.) Unilateral damage, not seriously injuring the vital cervical cord, can be repaired through a hemi-laminectomy. Some of the best results of spinal cord surgery have come through this procedure.

Occasionally, extreme and uncontrollable pain, even in the presence of a transected cord, was noted. This pain was radicular in distribution and was on two occasions intractable to re-operation, decompression of the proximal nerve roots

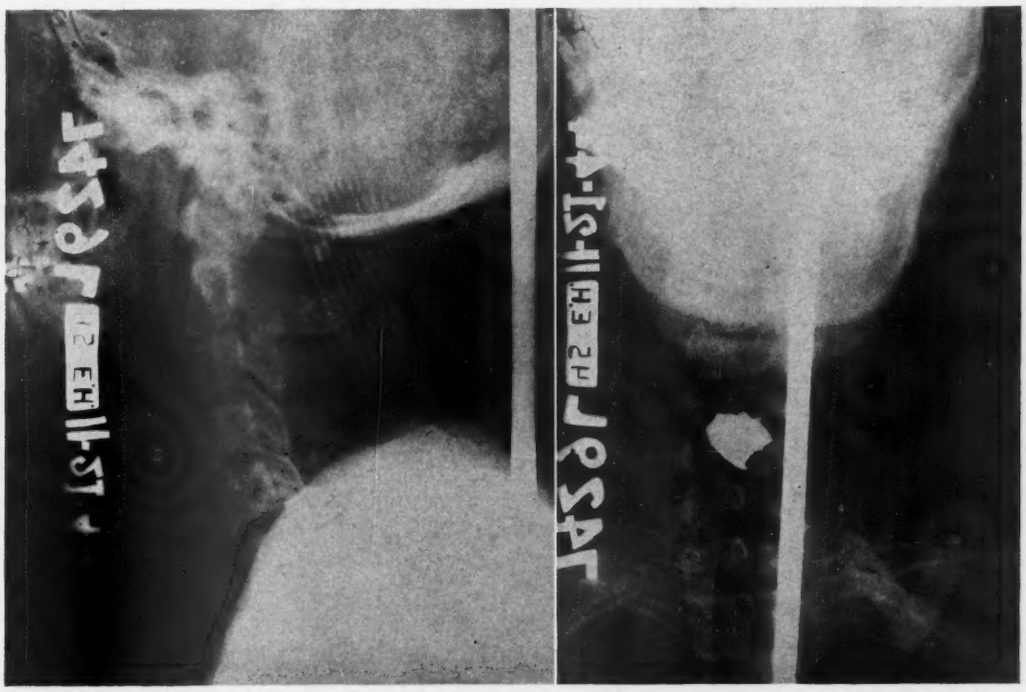

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FIG. 6. Large shell fragment crossing neural canal at C5-6-7, transecting cord and causing death.

and even posterior rhizotomy. Intrathecal alcohol had no effect on the pain nor did sympathetic paravertebral blocks. It is believed cordotomy may be indicated in such cases. Ammonium salts intrathecally (Pitcher plant extracts) may have been of some value.

The problem of severe and painful flexor spasms or mass reflexes was not seen in this early phase. Therefore, the need to consider anterior or posterior rhizotomy, nerve crushing or the use of curare, did not arise.

Technic does not vary from accepted technic anywhere. Local anesthesia is used frequently but endotracheal gas-oxygen-ether, and even sodium pentothal, is also commonly used. The dura mater is always opened unless the wound is dirty or old. There need be no fear of meningitis with the adjuncts of penicillin and sulfonamides.

TABLE I*

	Pts.	Operated	Incomplete Physiol.	Complete Physiol.		Preop. Deaths	Postop. Deaths	Over-all Mort. Rate	Postop. Mort. Rate	Some Ret. of Function (6 Wks.)
				Anat. Comp.	Anat. Incomp.					
Cerv.....	35	10	3	3	4	10	3	37.1	30.0	7
Dors.....	81	29	6	5	18	2	3	6.1	10.3	8
Lumbar.....	66	35	8	4	21	0	0	0.0	0.0	14
Sacral.....	2	2	0	0	2	0	0	0.0	0.0	1
Total.....	184	76	17	12	45	12	6	9.8	7.9	30

* Those patients not operated upon were adjudged to have had their spinal cord transected or battle conditions were such as to make laminectomy not feasible. Very rarely did the general condition of the patient contraindicate surgery. Postoperative cervical deaths were due to transected cord. Postoperative dorsal cord deaths were due to abdomen-chest wounds. Cervical cord wounds that survived and improved had had hemi-laminectomies; four so-called "supersonic concussion of the cord" cases improved without surgery in eight to forty-eight hours. Only three of twenty-nine spinal cord wounds were operated upon in the Mediterranean Theatre.

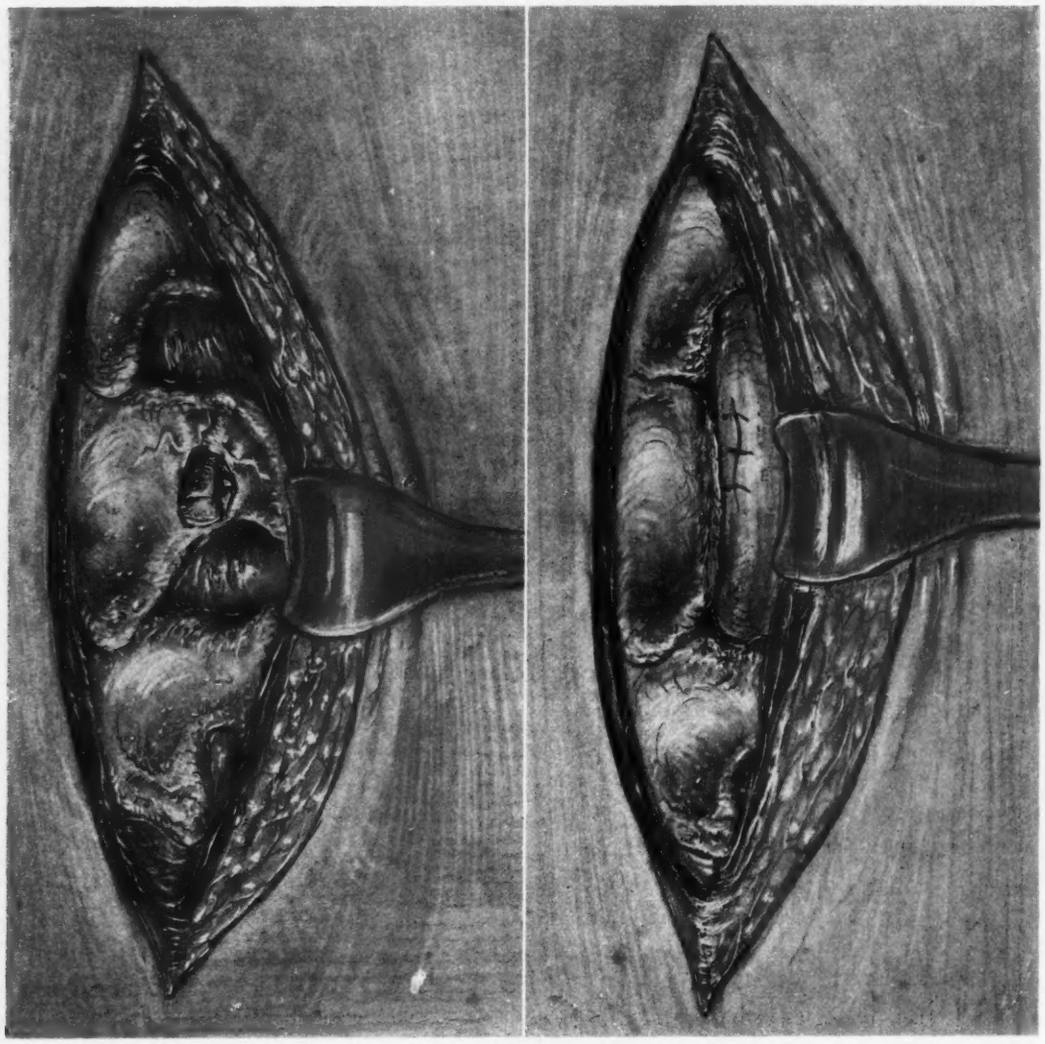

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FIG. 7. Hemi-laminectomy necessary for removal of missile in Figure 3. Illustration was developed from author's operative sketch.

The author has seen no infections in this series. Local sulfonamides and penicillin were instilled. Tight dural closure without drainage is always performed. The dura is closed with a fascial graft if necessary.

PROGNOSIS

Study of Table 1 will reveal an over-all mortality of all patients with spinal cord wounds reaching the neurosurgeon alive of 9.8 per cent. Postoperative mortality rate was 7.9 per cent. Cervical cord wounds caused a 37.1 per cent death rate, over-all, and 30 per cent postoperatively. The mortality rate of dorsal cord wounds was 6.1 per cent over-all, and 10.3 per cent postoperatively. Lumbar and sacral wounds caused no deaths. These rates are calculated on a ten-day period and constitute immediate mortality. Those patients with transected cords may survive for varying periods until the usual bladder or decubitus infections are fatal. Although tidal drainage was used on all bladders in the early phase, it was rare that a patient with a spinal cord wound reached the United States without a suprapubic cystotomy. This is not an indictment *per se* of tidal drainage apparatus, since facilities and personnel for constant supervision were lacking.

Seventy-six laminectomies revealed only twelve transected cords; 108 patients, how-

ever, had been rejected as being inoperable because of a transected cord.

Thirty patients had a return of function of some degree following laminectomy. No return was noted in patients not operated upon, except in four patients with concussion of the cord and no bone damage. Seven patients with cervical cord wounds recovered function, everyone whose cord had not been severed. Eight patients with dorsal wounds recovered function, twenty-one did not and three died. Fourteen patients with cauda equina lesions had a return of function out of thirty-five patients operated upon; twenty-one did not, but none died. Thus, of the seventy-six patients laminectomized 18.4 per cent (fourteen patients—four cervical, three dorsal and seven cauda equina lesion) had some return of function within ten days. Within six weeks 39.4 per cent had a return of some function. Further follow-up has not been done as yet. It is believe that improvement may continue up to one year. Therefore, it may be assumed that a greater percentage will be eventually benefitted. The author believes strongly that proper and prolonged care and rehabilitation of these unfortunates may allow some progress in the over-all picture. Complete and exacting study and care of skin, bladder and general condition may allow technical rehabilitation to the point of social usefulness. It may also allow a healthy mental readjustment, a much needed ally of the physician. Postoperative deaths occurred only in those patients with severe associated wounds, except for the cervical cord wounds, who died quickly of respiratory failure.

SUMMARY

Pessimistic attitude regarding spinal cord wounds has been recounted. Gradual shift of opinion has led to increased number of laminectomies and fairly encouraging results. Unreliability of clinical signs and *x*-rays as to cord section is emphasized. Prognosis as to life and return of function after laminectomy is evaluated. Indications for laminectomy and hemi-laminectomy are described. A careful and exacting study, care and rehabilitation program is indicated, and may provide a clue for further improvement.

CONCLUSIONS

1. Anatomically transected spinal cords are fewer, in gunshot wounds of the vertebral column, than formerly believed.
2. Physiologically transected cords may recover if compression is relieved by early surgery.
3. Early laminectomy is indicated if any question exists as to sparing of the spinal cord.
4. It is believed that all cauda equina lesions should be explored.
5. Thirty-nine and four tenths per cent of seventy-six spinal cord wounds operated upon had some return of function in six weeks.

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MANAGEMENT OF WAR WOUNDS OF THE CRANIAL CAVITY

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IN the main, the general principles for the management of war wounds of the cranial cavity were established by Cushing during the first World War. The exigencies of war at time led to certain variations in the execution of these principles for the locations of the battle fronts and methods of evacuation of the wounded were not always the same. Events sometimes dictated methods and at times evolved new principles. It was necessary to take climate into consideration in the management of these patients. This was certainly true in the tropics. As would be expected, the time interval between wounding and the time definitive treatment could be given played a definite rôle in governing the type of therapy to be used. Because of these various factors, this report will be a general outline of the management of war wounds of the cranial cavity as experiences dictated them in the China-Burma-India Theater.

GENERAL

At the beginning of the campaign in North Burma, evacuation of the wounded was slow because of transportation problems. Thus patients with head wounds did not reach a hospital where definitive treatment could be given for three to five days or even more after wounding. The forward hospitals were not equipped to do this type of surgery but did some débridement and frequently closed the wound in order to tide the patient over days of transportation. Those wounds which were left open arrived at the neurosurgical center in relatively good condition although a few were infected. The closed wounds, on the other hand, were in a number of instances infected and these had to be opened. As a result of these observations and the fact that air evacuation of the wounded was subsequently established, an organized plan was set up for the handling of all head wounds.

Those medical units which had no equipment and were without trained personnel, such as the Portable Surgical, Field and Evacuation Hospitals, were instructed to administer shock therapy and emergency treatment to the wound. After the patient had reacted from shock, he was evacuated directly to the station where definitive therapy could be given. Cooperation was excellent and by the time the campaign reached its height these wounds were receiving definitive treatment within twelve hours after wounding, or within twenty-four hours at the very latest. This system worked so effectively that it seemed to us unnecessary to consider placing a Portable Neurosurgical Unit within the active combat zone. This was especially true since a battle front in the traditional sense did not exist in the jungle.

EMERGENCY TREATMENT

The therapy advised in the forward units was that the wounds be cleansed, that hemorrhage be controlled, and that the wound be dusted with sulfanilamide crystals and an appropriate dressing applied to the entire head. No penicillin was then available.

The head was to be shaved all about the wound for a minimum distance of three inches or, if time permitted, the entire head. The wound was to be washed with a sterile solution of soap and then irrigated with a sterile normal salt solution. Hemor-

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rhage from the scalp was to be controlled by suture ties and hemorrhage from the brain by gentle pressure with dry sterile cotton pledgets or ligation of the vessel if it could be seen. (No fibrin-foam was available in this theatre during the entire period of combat.) Following irrigation of the wound, the surface of the wound was to be dried and dusted with a light layer of sulfanilamide crystals. Sterile gauze dressings were to be applied to the wound, the head padded with gauze or cotton and the dressings covered by a gauze handkerchief and fastened moderately tight to the head by gauze bandage so that it would not come off during transit.

Procedures which were not advised were as follows: No excision was to be made of the scalp edges, dura or brain tissue unless they were very loosely attached. Bone fragments were not to be removed since they might be acting as a plug to a vessel or sinus which, when released, might cause uncontrollable hemorrhage. Plaster of paris or crinoline bandages were not to be used as a head dressing for these materials shrink while drying and necessitate cutting to prevent unbearable pressure which might easily endanger the blood supply to the scalp.

SHOCK THERAPY

Many of these patients were treated by elevation of the foot of the litter, while others were kept flat. No harm in the form of dangerously increasing intracranial pressure or the precipitation of hemorrhage seems to have occurred in those on whom the head-down position was used. In fact the reaction from shock seems to have been hastened without untoward effects. Thus observations made in many patients support the use of the head-down position in patients with wounds of the cranial cavity in the treatment of shock. A further advantage of this position is that in the unconscious patient it permits the secretions to collect in the nasopharynx from which they can be removed by wiping or aspiration.

It was rarely necessary to use more than one blanket during the day because of the tropical heat. In severe cases, and during the night of the dry season, when the air temperature dropped to 50°F. or below, it was necessary to use both blankets and heat.

Where blood loss was partially responsible for the production of shock, whole blood was definitely more effective than plasma, although the latter served well as an emergency measure for resucitation. It is surprising, in reviewing our records, to learn how few of the patients were given either plasma or blood. This is difficult to explain because many of the wounds were extensive, even though they were caused for the most part by small arms ammunition.

The use of intravenous fluids has been generally considered to be contraindicated in these patients. It was soon learned that this was not true. In the tropical climate most of the wounded were dehydrated and required fluids. Many of them, therefore, were given 500 to 1,000 cc. of sterile normal salt solution, with or without 5 per cent glucose. The intracranial pressure was not seriously increased and in fact, definite beneficial effects were seen from its use. From these experiences with the intravenous fluids in wounds of the cranial cavity more attention was given to the fluid balance of the patient and measures taken to maintain it.

The use of morphine sulfate in these patients was not recommended, although some did receive it. No particular complication followed its administration but the clinical picture was made more difficult to interpret. Our feeling is that morphine serves no useful purpose in the treatment of these wounds since pain is rarely a factor. Other drugs such as chloral hydrate and paraldehyde are more effective in the control of restlessness which is at times a serious complication.

AIR EVACUATION

It was our experience that head injuries stood air travel very well. Because of the

terrain the planes had to ascend to an altitude of at least five thousand feet during the trip. Only one patient had to be given oxygen during the flight. He was operated upon and made a good recovery from a rather extensive cranial wound. Although a few patients died while en route, it was quite obvious that air travel played no part in the course of the injury since the wounds were extensive and involved vital centers or large venous sinuses.

Frequently the large number of casualties and the perilous location of the forward medical unit made it necessary rapidly to evacuate the wounded. Patients with head wounds in varying degrees of shock were placed in the planes and transported to the neurosurgical center. Comparing the notes that came with these patients, and our own made at the time of arrival at the hospital, no significant alteration in the degree of shock was noted. Although this practice is not to be recommended, air transportation can be used for patients in moderate shock if conditions so demand, provided active treatment is continued during the period of evacuation.

A rigid vigilance was insisted upon over the unconscious patient during transit. Obstruction to breathing was to be prevented by keeping the patient on his side and if necessary the tongue to be drawn out of the mouth. Precautions were to be taken against the patient inspiring vomitus and against injury to the patient during a convulsion should these complications occur.

DEFINITIVE THERAPY

The principles of surgical treatment of penetrating, perforating and lacerating missile wounds of the cranial cavity which were used were: complete removal of all devitalized brain tissue, bone fragments and foreign bodies, water tight closure of the dura and closure of the scalp with drainage. Each of these structures—scalp, dura, bone and brain—will be discussed separately.

Before operation was begun three things were given consideration: The *first* of these was an *x*-ray film of the skull. This was made in nearly every patient with a scalp wound no matter how trivial or extensive. This examination gives valuable information in two respects, namely, the extent of the underlying bone injury and the location of the bone fragments and opaque foreign bodies. Occasionally the surgeon was warned of possible hazards during the operation in that the bone fragments or missiles could be seen to lie close to a major vessel or venous sinus.

If circumstances prevented an *x*-ray examination of the skull before operation or if there was any doubt following operation that an incomplete operation had been done, the examination was made postoperatively when the patient's condition permitted it.

The importance of following this procedure was brought to our attention very dramatically. A soldier entered the hospital four hours after receiving an extensive wound of the cranial cavity. The data which came with him stated that he had been hit in the left occipital region by the recoil mechanism of a 75 mm. Howitzer. His condition did not permit a preoperative *x*-ray examination of the skull. Practically the entire occipital lobe, part of the temporal and parietal lobes had been destroyed. The devitalized brain tissue was removed, hemorrhage controlled, the dura repaired and the scalp closed by counter-incision. Without any warning and without evidence of increased intracranial pressure the patient had a convulsion on the seventh day which began as a right Jacksonian seizure and became generalized. He never regained consciousness and died about seventy-two hours after the attack. At the autopsy the area of the wound was clean. In the left occipital lobe close to the region of the pineal gland there was a shell fragment almost 2 cm. in diameter. It was in the center of an abscess which had ruptured into the pineal fossa. This fragment could have been reached and easily removed, had it been known that it was

present. However, we were misled by the historical data which came with the patient. As a result of this experience, routine postoperative films were made of all cranial cavity wounds.

The *second* point is the question of deferring operation until the patient has fully recovered from shock. In general this is good practice. However, we soon learned that too much time should not be allowed to elapse before operation because the wound itself prevents the patient from fully recovering from shock. A case will illustrate this fact: A Chinese soldier with a moderately extensive frontal lobe penetrating wound was admitted to the hospital with a temperature of 96.8°F., pulse of 140, respirations 36 and blood pressure 90/40. No further delay seemed indicated so the wound was excised and repaired under local anesthesia while the patient was given fluids and plasma intravenously. Upon return to the ward he had completely recovered from shock, having a blood pressure of 104/60.

This occurred in a number of instances and strengthened our impression that the removal of blood clots, divitalized brain tissue, bone fragments, and foreign bodies and controlling hemorrhage is part of the treatment for shock, when conservative measures fail to give a satisfactory response.

The *third* point concerns itself with the time interval between wounding and operation. There is no question that these wounds should be treated surgically as soon as possible after they have been inflicted. In the beginning of our experiences these patients came to the hospital three to five days or even more after wounding. Many of the injuries appeared relatively clean and without odor. They were treated as if they were clean by excision and closure with drainage. At first the wounds were dusted with sulfanilamide crystals. Later the practice of using local sulfonamide therapy was discarded. We had independently come to the same conclusion as did Ascroft from his African campaign experiences. These wounds can be considered surgically clean up to forty-eight or seventy-two hours after wounding provided they appear clean. In fact Ascroft's results show that repairs done after twelve hours were attended with less complications than those done within the twelve hour period. Our results agree with his even though we were located in a tropical monsoon climate where it would seem that the opportunities were greater for the development of infection than on the tropical desert of Africa. In fact our observations lead us to conclude that wounds as old as five days which did not contain pus and had no odor could be treated as though they were clean.

These necessarily delayed operations were all treated by drainage of the scalp for a period of forty-eight hours or longer, depending on the amount of drainage. If infection did develop, it remained superficial and in no instance did a brain abscess, meningitis or osteomyelitis develop. This observation permits the conclusion that these wounds should not be treated until definitive surgery can be performed and as such are not the acute emergencies they were once thought to be, although the practice is not to be recommended for routine use in civilian practice.

SURGICAL TECHNIC

The *scalp* wound should be treated by excision of the edges back to healthy tissue. Conservatism should be exercised in this procedure because the scalp has a very rich blood supply and recovers remarkably well from injury. It is better to give questionably viable scalp tissue, where there is a possibility of re-vascularization, the benefit of the doubt rather than create defects which are large and extremely difficult to close.

The next step is the enlargement of the wound to provide adequate exposure of the bone defect and room to work upon the brain injury. This should be done with consideration of the blood supply and at least part of the plan for wound closure. If curved incisions in the form of a flap are

used, the base should include at least one of the four arteries of the scalp; supra-orbital, temporal, posterior auricular and occipital. A "tripod" exposure in which three radiating incisions are made from the wound is to be avoided because after closure the three opposing tips in the center invariably undergo degeneration and a hole results which must be repaired subsequently.

When there is a large defect the problem is at times very difficult. Many of these in our experience can be closed by a counter-incision. This means that when the original wound is enlarged, the extensions should be made in a straight or slightly curved line so that the counter-incision can be made parallel to it and a sufficient distance away to allow for blood supply as well as a wide enough strip to cover the bone defect. At least three inches should be allowed between the wound and the counter-incision. The latter does not have to be closed at the original operation but may be left open if the tension for closure is too great. In several of our patients in whom the counter-incision was left open closure took place without secondary operation. One in particular, in which the separation was at least three inches, closed leaving a scar of not more than three-quarters of an inch wide. The important thing in closing scalp defects is that the bone defect in every instance should be covered.

Bone. Bone should be removed to expose at least one inch of normal dura all about the defect. After this has been accomplished, the dural and brain lesion can be inspected and any additional bone removed for better exposure. When the bone defect is next to a venous sinus, it is best to start the procedure on the side away from the sinus and to make the opening rather large so that as the sinus is approached there is adequate room to take care of any injury to the sinus. In those instances in which a piece of bone has been driven in toward the sinus but remains attached to the intact skull edge, it is most important to leave the piece of bone attached until sufficient has been removed on either side so that the sinus can be reached directly for the control of bleeding. Bone defects involving the frontal sinus or near it, and including it by fracture lines should include a wide opening of the sinus and removal of its membranes. The finished bone defect should have smooth edges and all bleeding should be controlled by a minimum amount of bone wax.

Dura. The edges of the *dura* should be trimmed and it is almost always necessary to extend the defect. Care must be exercised when doing this not to tear cortical vessels or damage normal brain tissue.

There are two views as to how the dural opening should be handled: The British believe that the defect should be left open. Their results, according to the reports in the literature, would suggest that this method does not increase the percentage of complications. We, on the other hand, believe that the dural opening should be closed in every instance and this view is generally accepted by American neurosurgeons. The advantages of repairing the dura, we believe, are that when infection develops in the scalp wound, it will tend to prevent the infection from spreading into the brain surface. When these healed wounds are opened for plastic repair, the procedure is rendered easier because a normal tissue plan has been provided.

In dural defects which are so large that direct closure is not possible, a graft of either fascia or pericranium should be used. Although these free grafts work very satisfactorily, they have the disadvantage that they are not living tissue. To overcome this we often used a pericranial flap in which the base of the flap remained attached to the intact tissue. A great many of the defects could be closed using this method. A smaller number were repaired by a sliding pericranial graft made similarly to closing of scalp wound by counter-incision. This method had the advantage of an excellent blood supply and of exerting an outward pull on the dura, drawing it tightly against

the bone edges and preventing hemorrhage from the surface of the dura beneath the bone after it had been sutured in place.

Brain. Treatment of the brain wound must include removal of all devitalized brain tissue, blood clots, bone fragments, foreign bodies, metal fragments and meticulous control of hemorrhage.

In wounds which involve vital areas such as the visual, sensory, motor and speech areas, it is most important to remove only the devitalized tissue. However, all of it should be removed, for if any is left, it increases the degree of scar tissue or may form a liquified collection, both of which may cause convulsions. Its removal is best effected by a good suction apparatus.

Second only in importance to the excision of devitalized brain tissue is the extraction of all bone fragments and foreign bodies. A piece of bone left in the brain substance serves as an excellent nidus for the development of a brain abscess. Of the brain abscesses that developed following wounds of the cranial cavity in our series approximately half were associated with retained bone fragments. Metal fragments, we found, presented a different problem. Frequently they lodged in the brain substance at a distance from the wound of entrance making it necessary to extract them through a separate opening. In general we left missiles less than 1 cm. in diameter which were not easily reached whereas those which were larger were removed.

Meticulous hemostasis should be established before the procedure can be considered complete. For this purpose fibrin-foam is said to be unequalled by those who have used it. We have had no experience with it. The cavity of the entire tract should be irrigated with at least 200 to 300 cc. of warm, sterile, normal salt solution through an asepto-syringe or sufficient fluid to have the washings return clear. If the cavity is deep or the tract long, a catheter attached to a syringe simplifies the problem. The purpose of irrigation is to wash out all the detached brain tissue or other foreign material that has not been detected.

Closure. The first wounds which we treated were dusted with sulfanilamide crystals before closing. This practice was stopped because no particular benefit was observed by its use and the tissues did not seem to heal as well when this was done.

Fine black silk or cotton was used for closing both the dura and the scalp. In a few instances fine steel wire was used to repair the dura and it is believed this is a better material, for if infection should develop in the scalp and silk has been used, it is necessary to remove all of the sutures. The vertical interrupted mattress suture proved the best for scalp closure. The edges of the wound were accurately approximated and the sutures were removed at the end of five days.

The scalp should always be drained with rubber tissue for twenty-four to forty-eight hours.

POSTOPERATIVE CARE

Oral or parenteral chemotherapy should be used prophylactically in all these wounds. We used sulfadiazine in full doses because penicillin was not available at the time our initial casualties arrived. With its use a careful watch had to be kept over the fluid intake because renal complications were common in the tropics if the fluid intake was not adequate. This prevented the employment of dehydration and caused us to keep a careful fluid balance in the patient. The value of the drug is undisputed for a rapidly spreading streptococcic infection was almost never seen.

The postoperative care was not particularly different from the management of patients from whom tumors have been removed. A routine taking of temperature, pulse, respirations and blood pressure every half hour for the first twenty-four hours and then less frequently as the clinical picture indicated should be made in all patients. Besides increased intra-

cranial pressure the result of edema or hemorrhage, one must be constantly on the look out for infection. Cerebral edema responds in most cases to conservative measures such as lumbar puncture and dehydrating agents. If no benefits are derived from this treatment and the wound looks clean, it should be explored for the possibility of hemorrhage. A subtemporal decompression should be done, if no cause for the pressure is found.

A wound that appears to be infected should be partially opened; and if pus is recovered, the entire scalp wound should be opened, accepting the inevitable development of a cerebral fungus. The treatment of this condition is beyond the scope of this paper. The infection in the wound was controlled best in our hands by packing it with gauze sponges saturated with penicillin. These packs were renewed every six hours for a period of two or three days as the infection dictated. After the infection had subsided for about one week, a secondary closure was performed or the edges strapped together.

The unconscious patient demands constant expert nursing care. Among the special things which must be closely watched in patients with head wounds is the free passage of air. Partially obstructed air passages increase intracranial pressure. The patient should be kept on the side, never on the back. If this is not effective, the tongue should be drawn out or an airway inserted. Before mucus begins to collect in the trachea, the foot of the bed should be elevated so that it will drain into the nasopharynx from which it can be either wiped out or aspirated at regular intervals. Rotation of the patient should be done every two hours for it is in these patients that pressure sores develop with great rapidity. The incontinent patient should be treated with an indwelling catheter without further delay, for it simplifies nursing care especially when there is a large group of patients and personnel is short. Tube feedings should be instituted after the first twenty-four hours of unconsciousness and at least 1000 calories be given in each twenty-four hour period. At the same time careful watch should be kept over these patients for the development of complications such as postoperative hemorrhage, infection in the wounds, pulmonary and renal complications.

SUMMARY

A résumè has been given of our experience in the general management of war wounds of the cranial cavity during the Burma campaign. These experiences revealed that wounds could be treated as clean up to five days after wounding, provided they appear clean and have no odor, which is in agreement with Ascroft's report of his African experiences. All bone fragments and missiles 1 cm. in diameter or larger must be removed because they serve as a nidus for the development of an abscess. The local application of sulfonamides seemed to have no beneficial effect in preventing infection. Prophylactic oral or parenteral sulfonamide therapy or penicillin is essential in the treatment of these wounds and has practically eliminated the occurrence of spreading streptococcic wound infection. In a tropical climate it is more important to maintain a fluid balance in these patients than to place them on a régime of dehydration.

PENETRATING WOUNDS OF THE BRAIN*

MANAGEMENT IN AN EVACUATION HOSPITAL

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AT the onset of the first World War the operative mortality from penetrating wounds of the brain was 55 per cent. By the end of that war Cushing was able to report forty-six cases with an operative mortality of only 29 per cent. At the close of World War II the mortality from this type of wound was about half of Cushing's best figures.

What were the reasons for this improvement? The surgical principles employed were essentially the same as those used during the first World War, namely, débridement, arrest of hemorrhage and usually repair of dural defects. The slight variations of Cushing's technic were the result of modern innovations such as the electrosurgical unit and suction apparatus rather than fundamental technical variations.

There were more significant reasons for this reduction of the postoperative mortality. The advent of sulfonamide and penicillin therapy must have been a vital factor. The protection afforded by chemotherapy increased the "safe interval" for primary definitive surgery to such an extent that concepts accepted as late as the onset of World War II became out-dated. The performance of primary definitive surgery in well equipped, forward echelons was a contributing factor. An abundant supply of whole, citrated blood and dried plasma permitted long, shocking surgical procedures which otherwise would have proven fatal. Finally, the improved organization of medical echelons surely contributed to the results obtained.

All forward neurosurgery was not done by formally trained neurosurgeons. In some hospitals it was done by general surgeons with a limited neurosurgical experience. This report records a portion of the experiences of two medical officers who fell into the latter category. It is based upon 122 consecutive cases operated upon by the authors during a period of fourteen months in the Italian campaign.

During this period there were 12,501 admissions to the surgical service of the Eighth Evacuation Hospital. Of these, 8,660 were battle casualties. It is impossible to state accurately the total number of neurosurgical admissions. However, a total of 222 neurosurgical procedures were done during the same period. Approximately 200 of these were operations upon battle casualties. Hence nearly 3 per cent of battle casualties were neurosurgical in nature. Cranial surgery was performed upon approximately 200 patients. Among these, 139 had penetrating wounds of the brain. This represents slightly less than 2 per cent of battle casualty admissions.*

A penetrating wound of the brain is herein defined as that in which the meninges covering the brain have been lacerated, directly or indirectly by a foreign body.

Table 1 indicates the mode of injury. Shell fragment wounds were predominant. One hundred and eleven were penetrating and eleven were perforating wounds. It

* Seventeen of these patients were operated upon by visiting officers and therefore are not included in this report.

* From the surgical service of the 8th Evacuation Hospital. This report is a condensation of a paper by the same title read before the Anglo-American Neurosurgical Conference in Florence, Italy, March 20–22, 1945.

TABLE I

Mode of Injury	Patients
Shell fragment	96
Gun shot (rifle or m.g.)	9
Mine	7
Bomb	3
Grenade	2
Other	5
Total	122

will be noted in Table II that parietal wounds were the most frequent while frontal and temporal were next in frequence. There were fifteen craniofacial wounds.

TABLE II

Location of Wounds	Patients	Incidence, Per Cent	Mortality, Per Cent
Parietal	40	32.7	12.5
Frontal	22	18.5	15.0
Temporal	21	17.2	9.5
Craniofacial	15	12.2	0.0
Occipital	9	7.3	33.0
Frontoparietal	5	4.1	0.0
Temporoparietal	4	3.2	0.0
Frontotemporal	4	3.2	25.0
Biparietal	1	0.8	100.0
Bifronto-parieto-occipital	1	0.8	0.0
	122	100.0	

MANAGEMENT

Preoperative. Patients were seen in the shock tent by a member of the neurosurgical team. The general condition and prognosis were appraised. If shock was present, as evidenced by the blood pressure or pulse rate, it was first corrected by replacement therapy. This was seldom necessary. More often the patients had considerable mucus, blood, vomitus or bronchial secretion in the throat and every effort was made to clear the respiratory passages by lowering the head and repeated aspiration. When the patient's condition permitted, a brief neurological examination was performed, the wound was examined and he was taken to the *x*-ray tent for roentgenograms of the skull and any other areas necessary. Stereoscopic views were not available and usually only AP or PA and a lateral view of the skull were taken. He was then taken to the neurosurgical ward for preoperative care. At least 1,000 cc. of blood was cross-matched prior to operation. Chemotherapy was usually instituted before operation.

The time for operation was not based upon any given time interval, but rather it was deferred until the patient's condition appeared to be optimum. Two factors were of importance in determining the time of operation. First, the condition of the patient as determined by the character of the blood pressure, pulse and respirations and febrile reaction. The second factor was availability of operating facilities, i.e., an anesthetist, operating table, etc. Occasionally, other patients required priority in the operating tent. Fifty-two patients were operated upon less than ten hours after admission. (Fig. 1.) Seventy-one cases reached the hospital less than ten hours after injury. Eighty-nine patients were operated upon less than thirty hours after injury. However, the time interval between wounding and operation was twenty hours or more in seventy-two instances.

TABLE III

Anesthesia	Patients	Per Cent
Endotracheal ether	57	46.7
Local field block	41	33.6
Local and pentothal	18	14.8
Pentothal	4	3.3
Open drop ether	2	1.6
Total	122	100.0

Operative. (a) *Anesthesia:* Anesthesia was almost equally divided between local field block and endotracheal ether. Other coincidental surgery frequently required general anesthesia. Pentothal sodium alone was used only four times but occasionally a craniectomy was done by means of a local field block and then if there were other not too extensive wounds, pentothal sodium was used for the subsequent débridement.

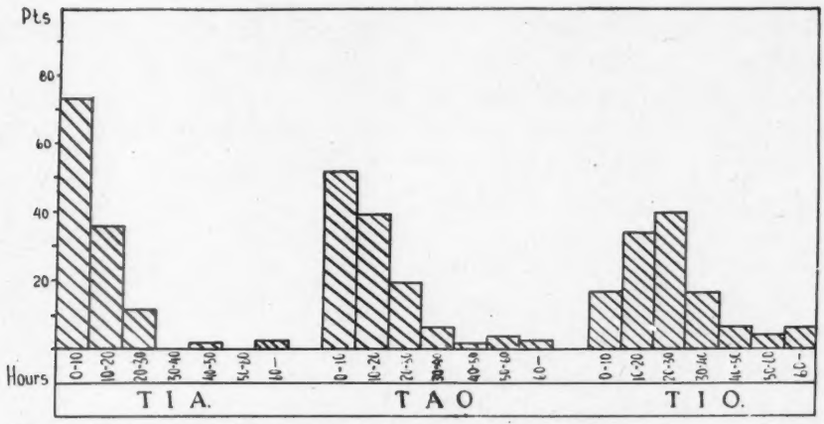

FIG. 1. This chart depicts the relative time intervals from injury to admission, (TIA); admission to operation, (TAO); and the total time interval from injury to operation, (TIO).

The relative use of the various types of anesthesia is listed in Table III.

(b) *Deferred Neurosurgery:* Neurosurgery was deferred for twenty-four to forty-eight hours in fourteen cases in which a craniocerebral injury was complicated by other serious wounds. In one instance, when pneumonia developed after primary surgery, craniectomy was postponed for nineteen days without apparent ill effect. However, in forty-three instances multiple surgical procedures were performed at one operation. The coincidental wounds encountered with penetrating wounds of the brain are shown in Table IV.

TABLE IV

Associated Injuries	Patients	Incidence	Mortality
		Per Cent	Per Cent
Multiple penetrating wounds	40	32.8	2.5
Major fractures	11	9.1	18.1
Thorax	4	3.3	25.0
Abdomen	1	0.8	0.0
Thoraco-abdominal	1	0.8	100.0
Total	57	46.8	

(c) *Craniectomy vs. Craniotomy:* Craniectomy was the most frequent procedure, having been performed in 111 cases. Craniotomy was reserved for craniofacial wounds and for removing foreign bodies which had traversed the brain. Craniotomy alone was done only five times. Both craniectomy and craniotomy were performed six times for removal of large, metallic foreign bodies at some distance from the wound of entrance.

(d) *Débridement:* Débridement included the removal of all débris and contaminated tissue from the scalp, cranium, meninges and brain substance insofar as possible. Adequate excision of all contaminated scalp was considered imperative. Concern regarding closure did not influence the extent of débridement. The removal of contaminated bone was likewise as complete as possible. Potentially infected meninges were excised. The débridement of brain substance included removal of all bone fragments, dirt and other foreign matter which could be identified. Débridement of the brain was accomplished by suction removal of soft, devitalized tissue. Bone fragments and metallic foreign bodies were usually removed after visualization. However, gentle palpation with one finger in the wound often identified bone or metallic fragments previously not visualized. No attempt was made to wash devitalized tissue or débris out of the brain wound. Irrigation of the wound was always performed with a cotton pledget in the brain cavity and then only to wash out small, remaining clots of blood.

Metallic foreign bodies were removed when safely accessible. Fifty-eight patients had one or more in the brain. Some were small and inaccessible. Others were fairly

large but had traversed the brain and required contralateral exposure for removal. At first, all these were left to be removed at an installation in the Base Area but later, contralateral craniotomies were done in six instances for removal of these foreign bodies.

(e) *Dural Closure:* The dura was closed in all except four cases. The various manners of closure are listed in Table v. Fifty-six preserved cadaver dura grafts* were employed. After their use was discontinued pericarnium was used most frequently. Fascia lata was utilized in eleven patients in whom a large graft was required. In only six instances did suture alone suffice.

TABLE V

Dural Closure	Pts.	Post-op. Abscess	Follow-up	Incidence of Abscess, Per Cent	Retained Bone Fragments	
					Yes	No
Preserved human dura	56	5	36	13.9	4	1
Autogenous tissue....	53	5	26	18.3	1	4
Pericranium 37						
Fascia lata 11						
Temporal fascia 5						
Suture plus muscle....	9	..	3			
Dura open.....	4	..	1			
Total.....	122	10	66	....	5	5

(f) *Scalp Closure:* The scalp was closed over the cranial defect in all but seven patients. It was possible to close the scalp simply in ninety patients. Thirteen required relaxing incisions and in twelve instances a scalp flap was rotated and a portion of the donor site left open. Primary skin grafts were not done. Tripod incisions and closures were avoided wherever possible. Seventy-nine wounds were closed with a small decompressive drain and forty-three were closed without drainage. (Table vi.)

TABLE VI

Wound Closure	Patients	Known Primary Healing	Per Cent	Known Wound Infection	Per Cent
Drain.....	79	50	63.2	14	17.7
No drain...	43	34	74.4	2	4.6
Total....	122	84	....	16	....

(g) *Chemotherapy, Local:* Local chemotherapy was employed in forty-nine cases. Sulfanilamide crystals were left in the brain, under and upon the dura in twenty-six instances. Penicillin was used intracerebrally in twenty-three patients. After the latter became available it was used in all cases of ventricular penetration.

(h) *Blood Loss:* Blood loss was replaced as it occurred. Five hundred cc. of citrated, whole blood was always given during operations and occasionally as much as 1,500 cc. was required. Overwhelming or even dangerous hemorrhage was rarely encountered except in injuries of the vascular sinuses or ventricular system.

Postoperative. (a) *Position:* The head of the cot was usually elevated for at least five days after operation. When the patients were unconscious or semi-comatose the foot of the cot was elevated for thirty minute periods to promote tracheobronchial drainage. At the end of these periods the throat was thoroughly aspirated.

(b) *Diet:* Diet was determined by the condition of the patient. If he could eat he was given a full diet and encouraged to eat as soon as possible. Those unable to eat were given parenteral fluids including at least one unit of plasma daily. The remainder of the fluids consisted of 10 per cent dextrose in water to which were added vitamins B and C. Tube feedings were seldom given.

* Employment of preserved cadaver dura was suggested to the authors in November, 1942, by Major (then Captain) Ralph M. Stuck, M.C., A.U.S. It was obtained from any necropsy in which there had not been an intracranial infection, neoplastic disease, acute or chronic systemic infection. The dura was removed and washed in running water to remove all blood clots. The venous sinuses were excised. Only that dura covering the cerebral hemisphere was preserved. After thorough washing, the tissue was placed in 70 per cent ethyl alcohol where it was stored until ready for use. At the operating table it was washed for thirty to forty-five minutes in normal saline solution. The tissue was then cut to overlap, by a narrow margin, the dural defect and anchored in place with four to six sutures.

(c) *Chemotherapy, Systemic:* Chemotherapy was continued for at least seven days. Sulfonamides or penicillin was given to all patients. The first thirty patients were given sulfadiazine, by mouth or intravenously, and penicillin was administered to the remaining ninety-two. When pulmonary complications were present or threatening, or when a meningitis developed, sulfadiazine was used to complement penicillin.

(d) *Early Ambulation:* The practice of early ambulation endorsed by the authors in 1943 for patients with cerebral concussion was followed in these cases as well. Patients were allowed out of bed whenever they felt able. A few were ambulatory the first day after operation and many before the fifth. This routine was followed even with those who had wounds of the vascular sinuses.

(e) *Discharge Examination and Evacuation:* Before evacuation to the Base Area patients were given a thorough neurological examination whenever time allowed. In addition postoperative roentgenograms of the skull were made to identify retained foreign bodies, especially bone fragments.

Most of these patients were held for nine or ten days before evacuation. Eighty-four were not evacuated until the ninth postoperative day or later and only five were transferred before the fifth day.

(*f*) *Follow-up:* Two v-mail forms on which was mimeographed a brief neurological outline with space for other pertinent postoperative data were enclosed with the patient's record as he left the hospital. One copy was returned from the Base Area in the Theater of Operations and the other from the Zone of the Interior. A follow-up was obtained on sixty-five patients.

COMPLICATIONS

Operative. (a) *Vascular Sinus Injuries:* The vascular sinuses were penetrated or perforated in at least nineteen cases. (Table VIII.) Despite the fact that six of the nineteen patients died, the sinus injury was a contributing factor in only two instances. In both of these the middle third of the superior sagittal sinus had been destroyed, requiring ligation.

(b) *Ventricular Injuries:* Undoubtedly some ventricular wounds were not recognized at operation. Only twelve in this group were known to have had such a complication. (Table VII.) Both bone and metallic foreign bodies were removed from the ventricular system. After it was available, intracerebral penicillin was used routinely in these patients and usually administered intrathecally as well after operation. Brain abscess occurred in three of this group, an incidence of 25 per cent. Intraventricular hemorrhage caused the death of one patient. Six others in this group died but the ventricular injury was not the pertinent factor.

TABLE VII

Complicating Wounds	Patients	Incidence	Infection Per Cent	Mortality Per Cent
Vascular Sinus.....	19	15.5	15.8	31.5
Sagittal.....	13	10.7	....	46.1
Lateral.....	6	4.9	....	0.0
Air Sinus.....	17	13.9	15.4	11.8
Frontal.....	17	13.9		
Ethmoid.....	8	6.6		
Maxillary.....	4	3.3		
Sphenoid.....	3	2.4		
Ventricle.....	12	9.9	25.0	58.7
Lateral.....	12	9.9		
Third.....	2	1.6		

Postoperative. (a) *Cerebral Edema:* During the first nine months of this period concentrated plasma was routinely used twice daily for five days after operation. It had been presumed that this was an effective means of controlling cerebral edema. However, this practice was abandoned in the last fifty cases. No differences were noted in the postoperative course in any respect, including the pulse rate and blood pressure recordings.

Lumbar puncture was used principally as a diagnostic procedure and rarely as a therapeutic aid.

(b) *Convulsions:* Eight patients had convulsive seizures or an incidence of 7 per cent. Only one of the eight had more than one. Three of these were among those who died and the fits were related to extensive brain damage or uremia. Despite the fact that convulsions within the immediate postoperative period are usually of diagnostic importance, only one of the remaining five was known to have required subsequent operation. In that case a brain abscess was recognized but an immediate hospital move necessitated evacuation of the patient.

(c) *Wound Infection-relation to Drainage and Chemotherapy:* Thirteen per cent of these patients were known to have developed wound infections. Eighteen per cent of those wounds drained became infected while only 5 per cent of those closed without drainage are known to have developed infection. (Table VI.)

Eight per cent of those patients in whom sulfanilamide crystals were used locally were known to have developed infection. Of the twenty-three patients in whom penicillin was used intracerebrally 26 per cent were known to have developed subsequent infection. No untoward effects were noted from the local use of either agent.

Sulfadiazine or penicillin was given systemically to all patients. But the presence or absence of infection could be determined in only 104 of the group, the remainder being evacuated or having died before healing had had time to occur. The results were observed in twenty-seven patients who received sulfadiazine. Eleven per cent became infected. The results were observed among seventy-seven patients receiving penicillin. An incidence of 13 per cent infection occurred in the latter group.

(d) *Brain Abscess:* Eleven brain abscesses were known to have developed in this group of patients. This represented 17 per cent of the 65 living patients on whom we had a follow-up. Five of these were diagnosed and operated upon before evacuation and the remainder underwent subsequent operation in a general hospital in the Base Area. Three of the former abscesses contained large, gram-positive bacilli but none resulted in gas gangrene and all recovered after drainage.

Table V also indicates the incidence of abscess in relation to the type of dural graft employed and also denotes the frequency of demonstrable bone fragments in the abscesses. There was essentially the same incidence of abscess among those patients in whom autogenous grafts had been used and those in whom preserved cadaver dura was employed. Bone fragments could

TABLE VIII
ANALYSIS OF DEATHS

Patient	Operation	Day of Death	Notes
R. P.	Craniectomy	Po, 10	Hemoglobinuric Nephropathy
J. W.	Bi-parietal craniectomy	Po, 9	Uremia-Sulfadiazine Intoxication
W. Z.	Craniectomy Debridement F.C.C. femur	Po, 2	Irreversible Shock
A. W.	Craniectomy	Po, 1	Hypothalamic Syndrome
M. R.	Craniectomy	Po, 2	Hypothalamic Syndrome
S. S.	Craniectomy	Po, 5	Metallic Foreign Body in Lateral Geniculate Body
F. C.	Craniectomy Thoracotomy	Died on Table	Air Emboli
E. N.	Craniectomy Hip Spica	Po, 2	Fat Emboli
T. P.	Craniectomy	Po, 3	Sagittal Sinus Ligation-Middle Third
L. C.	Craniectomy	Po, 4	Sagittal Sinus Ligation-Middle Third
I. B.	Craniectomy	Died on Table	Carbon Dioxide Intoxication
D. W.	Craniectomy	Po, 1	Post-Lumbar Puncture. Cerebellar and Uncal Herniation at Necropsy
N. W.	Craniectomy Craniotomy	Po, 5	Pneumonia and Lung Abscesses
L. F.	Craniectomy	Po, 3	Overwhelming Cerebral Trauma
H. S.	Craniectomy Trephine for removal MFB	Po, 3	Ventricular Hemorrhage

be identified by *x*-ray or at operation in only half of the abscesses. Metallic foreign bodies retained in the brain were not a contributing factor in any of the known abscesses in this series.

Mortality: One hundred fifty patients with penetrating wounds of the brain reached the hospital alive. One hundred twenty-two were operated upon with fifteen deaths or an operative mortality rate of 12.3 per cent. Some patients who were evacuated died in the next installation to the rear. Six of this group died in a general hospital in the Base Area which is about the usual mortality rate in general hospitals for this type of case. The postoperative deaths are summarized in Table VIII.

SUMMARY

1. One hundred twenty-two patients with penetrating wounds of the brain who underwent primary definitive surgery at an evacuation hospital during fourteen months of the Italian campaign are reported. Less than 2 per cent of battle casualties reaching this evacuation hospital had such an injury. The total mortality rate of all patients with penetrating wounds of the brain who reached the hospital alive was 29 per cent. The operative mortality rate was 12.3 per cent.

2. The factors influencing the decrease in the operative mortality rate during World War II are thought to be chemotherapy, blood replacement and earlier primary definitive care.

3. Aspiration of vomitus, blood or bronchial secretion was a frequent complication. Such a complication required vigorous treatment. Evacuation in the coma position was an aid in preventing aspiration.

4. Surgery upon these patients was deferred until they presented the optimum preoperative condition. Decompression was seldom urgent.

5. Local field block or endotracheal ether were the anesthetics of choice.

6. In general, craniectomy was preferable to craniotomy.

7. Débridement of all involved tissue was considered imperative.

8. Dural closure was preferred in all cases in which a satisfactory débridement of the brain had been accomplished.

9. The tissue used to close a dural defect did not appear to be an important factor in the development of post-traumatic brain abscess. Retained débris or bone fragments were apparently more important factors than the type of graft.

10. Penicillin and sulfadiazine seemed to be about equally efficacious in preventing and controlling infection in craniocerebral wounds.

11. Every effort was made to close the scalp over cranial defects. Drainage of scalp wounds would appear to be contraindicated.

12. Except for injury of the mid-portion of the superior sagittal sinus, vascular injury was not a serious complication.

13. The involvement of air sinuses in craniocerebral wounds was not a serious complication with respect to infection or mortality.

14. Ventricular injury was a serious complication despite the chemotherapy available.

15. The use of concentrated plasma did not objectively alter the postoperative course of these patients.

16. No undesirable effects were noted from early postoperative ambulation.

SURGICAL PROBLEMS IN THE LATE MANAGEMENT OF CRANIOCEREBRAL INJURIES WITH SPECIAL REFERENCE TO THE REPAIR OF CRANIAL DEFECTS WITH TANTALUM PLATE*

AN ANALYSIS OF 170 CASES†

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IN contrast to the circumstance that has heretofore obtained in military medical history, relatively large numbers of patients presenting the late sequelae of craniocerebral injuries have been evacuated during World War II to hospitals in the Zone of the Interior. Statistics bearing reference to the actual numbers of these cases have not been published as yet by the Office of the Surgeon General. The factors that subtend the circumstance are, however, readily recognizable and include the following: (1) High speed evacuation of the injured to surgical installations at which early definitive care is instituted; (2) the exercise of sound neurosurgical principles and meticulous technic by surgeons in the forward zones; and (3) planned chemotherapy, both prophylactic and therapeutic. These three factors have made it possible to preserve life in numerous instances in which the patients heretofore must have succumbed to head injuries and their complications.

It is the purpose of this paper, to set forth the chief problems encountered at a neurosurgical center in the Zone of the Interior, to indicate the modes of their management and to summarize the results insofar as early follow-up permits expression thereof.* The bulk of cases fall into the following categories: (1) skull defects, (2) infections, (3) intracranial foreign bodies, (4) convulsive seizures, (5) neurological defects (other than convulsions), and (6) the postcerebral concussion syndrome.

SKULL DEFECTS

During the period of two years ending in September, 1945, 170 patients were encountered with defects of sufficient clinical significance to require surgical repair. The defect was principally in the parietal region in fifty-seven of these, in the temporal region in forty-nine, in the frontal region in forty-seven and in the occipital region in seventeen patients. (Table 1.)

By far the commonest original cause of the bony defect was a penetrating head wound followed by débridment. There were 130 such cases. Among the remainder, sixteen were defects as the result of débridement of compound skull fractures and/or depressed fractures of the vault not due to penetrating wounds; six were the result of débridement for osteomyelitis (paranasal sinusitic and hematogenous in origin) of the skull; five were the result of evacuation of subdural hematomas; and three were the result of evacuation

* Psychiatric sequelae as such and neurological sequelae of the sort that fall under the care of the ophthalmologic and ear-nose-throat services will not be dealt with here.

* From the Neurosurgical Section of the Mayo General Hospital, Galesburg, Illinois. Presented before the Chicago Neurological Society, March 13, 1945, and before the neuropsychiatric conference of the Sixth Service Command, November 17, 1945.

† Publication of this paper was aided by a grant from the Ethicon Suture Laboratories, Division of Johnson and Johnson, New Brunswick, N. J.

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TABLE I
THE RELATIONSHIP OF THE LOCATION OF THE SKULL DEFECT TO THE MOST PROMINENT NEUROLOGICAL DEFICIT

Neurological Sequelae	Parietal Skull Defect	Frontal Skull Defect	Temporal Skull Defect	Occipital Skull Defect
No clinical sequelae	12	23	15	1
Euphoria	3	6	0	0
Syndrome of the trephined	7	6	11	3
Mild unilateral hemiparesis	15	8	8	2
Hemiplegia	8	0	6	1
Hemiparesis or aphasia	9	4	8	0
Paraplegia	1	0	0	0
Triplegia	1	0	0	0
Quadriplegia	1	0	0	0
Hemianopsia alone	0	0	1	10
Total	57	47	49	17

of extradural hematomas. In one instance the defect was due to drainage of a so-called spontaneous brain abscess, and in one case the defect resulted from a subtemporal decompression, the reason for which could not be ascertained because the clinical record had been lost in transit. (Table II.)

TABLE II
THE ETIOLOGICAL AGENTS IN THE PRODUCTION OF THE SKULL DEFECTS IN THIS SERIES

Débridement of penetrating head wound	Débridement of osteomyelitic areas of the skull	Débridement of compound skull fracture not due to penetrating wound	Evacuation of extradural hematoma	Evacuation of subdural hematoma	Débridement of spontaneous brain abscess	Subtemporal decompression cause undetermined
138	6	16	3	5	1	1

In this series the defect repaired varied in diameter between 2 and 14 cm., the average being approximately 5 cm. In eight patients it was required to deal with more than one defect.

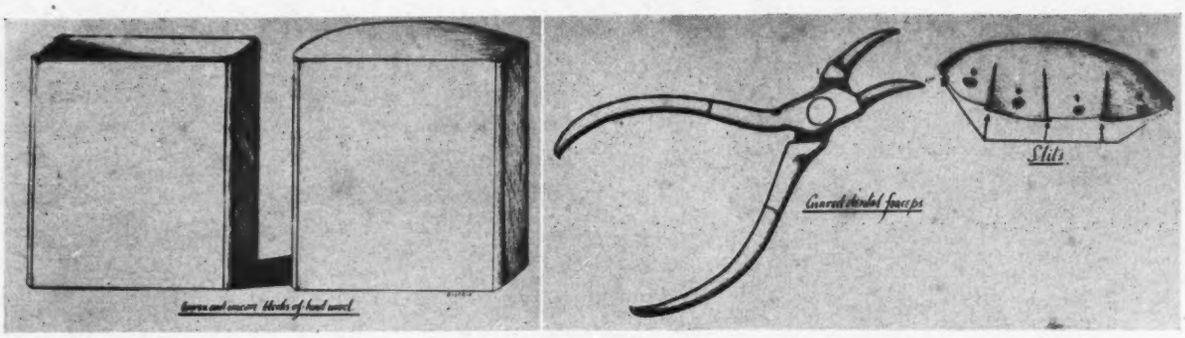
The indications for cranioplasty were considered to be as follows: (1) Pulsating defects anywhere in the vault measuring 3 cm. or more in diameter; (2) disfiguring frontal and frontotemporal defects, irrespective of size; (3) defects unduly sensitive to pressure irrespective of size; (4) defects covered with a thin layer of scar tissue (such scars were excised at the time of cranioplasty); (5) defects in patients presenting the postconcussion syndrome; (6) defects in patients who complained of a feeling of insecurity because of the presence of a vulnerable area in the head; and (7) defects in patients needing surgical exploration for other reasons (e.g., removal of metallic or bony foreign bodies, resection of meningocerebral scar and the uncapping of porencephalic cysts).

By far the most frequent reason for carrying out cranioplasty was the presence of a pulsating defect. The next most frequent reason was cosmetic. A numerical account of the reasons for which cranioplasty appeared to be indicated in the four main regions of the vault (frontal, parietal, temporal and occipital) among the patients in this series is given in Table III.

The material used for repair of the skull defects in all cases of this series was tantalum. This is a non-magnetic, metallic element, the relatively inert chemical and electrical characteristics of which render it highly adaptable to implantation in biological tissues.[1–5] In plates of .0125 and .015 in. thickness it lends itself readily to molding, cutting and swedging and not its least merit is that contour cranioplasty can be carried out at a single procedure. The only contraindication to its use is the presence of infection. The technical considerations that pertain to the use of tantalum will be dealt with under four headings: (1) The preparation of the plate; (2) a consideration of tissues (scalp, muscle, meninges, brain) in contact with the plate; (3) postoperative fluid collections and their management; and (4) insertion and fixation of the plate at operation.

PREPARATION OF THE PLATE

At the outset, the tantalum plates used in the repair were fashioned at the operating table after the skull defect had been surgically exposed. The technic consisted of first, cutting out a plate, using heavy



A B

FIG. 1. A, convex and concave blocks of hard wood over which plate may be fashioned by hammering. B, a rapid method of shaping tantalum plate at the operating table.

shears, with all pointed edges of the plate rounded off. Usually the plate was cut to overlap the edges of the defect about 5 mm. Cognizance was then taken of the contour of the skull at that point, following which the plate was beaten out with a mallet, to the required curvature on concave and convex blocks of hard wood. Adequate but not accurate contour could thus be obtained. (Fig. 1A.)

Another more rapid method of shaping the plate at the operating table is that of cutting perpendicular slits about 6 mm. long in the plate, along its periphery at intervals of approximately 1 cm. With a curved dental forceps, it becomes relatively simple to give adequate curvature to the plate. (Fig. 1B.)

The most obvious disadvantage of both these methods is that unnecessary time is consumed at the operating table in their preparation. Another disadvantage, previously mentioned, is the fact that although the plates are adequate they are not as cosmetically accurate as those which are prepared by swedging the plates from plaster molds. This latter technic is easily mastered and can be used wherever a dental laboratory is available. It consists of six steps:

TABLE III

AN ANALYSIS OF THE REASONS UNDERLYING THE NECESSITY FOR CRANIOPLASTY IN THE VARIOUS PARTS OF THE HEAD

Chief Indications for Repair	Location			
	Parietal	Frontal	Temporal	Occipital
Pulsating defect, 3 cm. or over	25	?	30	12
Disfiguring defects	7	47	14	3
Skull defect tender to the touch.	1	There were other indications for repair of many of the frontal defects, but the cosmetic factor was considered sufficiently important in itself	0	0
Thin scar over defect	3		0	0
Syndrome of the trephined	8	?	2	1
Surgical exploration necessary for other reasons.	9 (removal of depressed bone fragments) 3 (removal of shell fragments)	?	5 (elevation of depressed bone fragments)	1 (removal of foreign body)
Feeling of insecurity, etc.	2	?	0	0

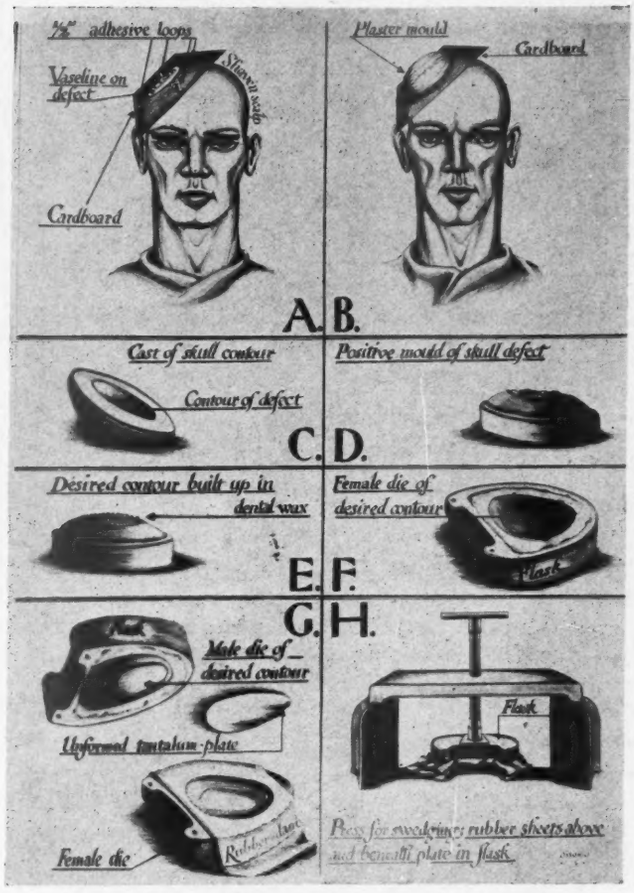


Fig. 2. Illustration of the steps necessary in the preparation of a tantalum plate from a plaster mold of the skull defect.

Step 1. The patient's head is carefully shaved so that the scalp is smooth. The skull defect and an area about three inches around it are then smeared lightly with vaseline and sufficient plaster of paris applied to make a thick negative impression of the skull defect. The plaster is applied over a card board crown which has, affixed to it, small ½ inch adhesive loops which facilitate the sticking of the plaster to the crown. The vaseline facilates the removal of the plaster cast. (Figs. 2A and B.)

Step 2. A positive impression (Fig. 2D) is then made of the negative cast. (Fig. 2C). This impression is an accurate reproduction of the patient's skull defect.

Step 3. The contours of the normal side of the skull are then carefully studied following which, with dental wax, the defect is filled to correspond accurately with them. (Fig. 2E.)

Step 4. A die of dental stone is then made from this model in a metal flask and when the stone has hardened, a counterdie is poured into the other side of the flask. (Fig. 2F.)

Step 5. The *x*-rays are studied carefully and the defect palpated through the scalp following which the surgeon marks out on the scalp the amount of overlap desired. This mark is copied accurately on to the prepared die and a piece of tantalum is cut to an approximately 2 mm. greater diameter than this, in order to take up the diameter lost in curving the metal. (Fig. 2G.)

Step 6. The tantalum is covered on both sides by dental rubber dam placed between the die and counterdie, following which in the case of small defects, the plate is swedged by pressure from an ordinary hand press. (Fig. 2H.) If a large plate is being made, a larger, heavier,

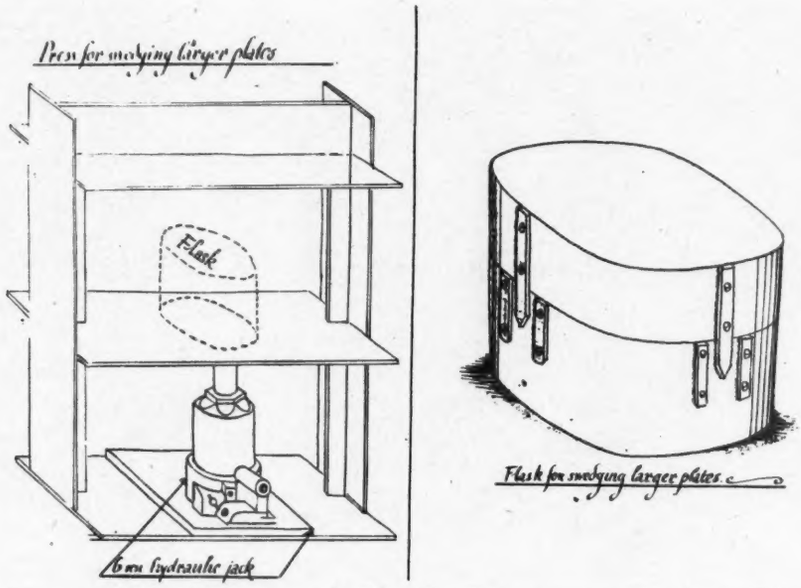


FIG. 3. A schematic representation of the apparatus employed in the swedging of large tantalum plates. The jack underneath the platform may be any type of ordinary automobile jack.

metal container (flask) is necessary for the die and counterdie, with interlocking metal tongues. The pressure apparatus is a simple device composed in effect, of a square of railroad steel bars for counterpressure and a hydraulic jack capable of six tons of pressure under the platform. (Fig. 3.) It is advisable to scratch directional guides on the surface of the plate, such as A for anterior and corresponding letters for posterior, right and left. This procedure facilitates orientation of the plate during operation.

In the procedure now being employed at this hospital, a number of small holes, 2 mm. in diameter, are drilled in the mid portion of the plate. Although not used by the author, an overhanging ledge about 1 mm. deep around the periphery of the plate is said to increase the strength of the plate.[6]

The temporal muscle renders it almost impossible to obtain an accurate cast of the skull defect when one exists in this region. However, a close approximation can be prepared before operation by swedging, and minor alterations can easily be made at the time of operation by cutting a few slits in the periphery of the plate and shaping it with curved pliers. (Fig. 1B.) Excellent results may thus be obtained.

CONSIDERATION OF THE TISSUES IN CONTACT WITH THE PLATE

In those cases in which the previous operative scar is not wide and is of adequate length for exposure of the defect, it has appeared advantageous to employ it as the site of incision, since it is less vascular, because it eliminates the necessity of producing another scar, and because it does not further compromise the blood circulation. On the other hand, if the patient's original injury was severe with marked destruction of the scalp and cranium, there is often a wide scar less than a millimeter thick, intimately adherent and largely dependent for its blood supply on the underlying dural or cortical scar. In such cases it is important to remember that death of this scar is inevitable if the tantalum plate is interposed between it and the cortical or dural scar because of insufficient blood supply. No hard and fast rules can be laid down as to the width and thickness of scar which can survive with a tantalum plate underneath it. It has been our experience that solid, relatively avascular

A B

FIG. 4. An illustration of two methods which were used to allow for space taken up by the resection of a very wide scar: A, a relaxing incision made away from the original scalp flap; B, a relaxing incision made by reopening the limb of the flap away from the tantalum plate; both healed well.

scars less than 3 mm. thick and more than 1 cm. square will not generally survive. In such a case, the scar shoud be excised down to the periosteum. The scalp is then mobilized to take up the space lost. It is essential that the scar be excised fully in order that a full thickness closure through galea and skin may be accomplished. If this is not accomplished, especially if there is slight tension at the suture line, the area over the tantalum will not heal.

It is of interest to note that in three cases in this series in which the scar (for the above reason) broke down over the tantalum, no infection intervened, although the bare tantalum plate was exposed over a period of weeks while conservative therapy in the form of heat, moist dressings and chemotherapy was being attempted.

The most satisfactory exposures were obtained by employing an orthodox scalp flap. Obviously, care must be taken to outline the scalp flap in the vicinity of the old scar so as not to embarrass the circulation.[3] Emphasis must be placed once more on the fact that, if a wide scar is present, even though the incision is not through it, if the tantalum plate lies under it, circulation may be sufficiently embarrassed to cause breakdown of the scar where it is thinnest and obviously nourished from underlying structures. The wisest procedure in our experience has been to resect it first, allow the wound to heal with a little vascular help from underlying structures, and then turn a scalp flap. In those cases in which the scar is of questionable viability, little is lost in turning a scalp flap, inserting a tantalum plate, and waiting to see if it will survive. Here, however, one must be certain to turn a generous flap such that, should the scar break down, it still may be excised from the center of the flap and perhaps one limb of the flap reopened to serve as a relaxing incision. The latter subsequently heals by granulation growth. (Fig. 4B.) Obviously if the bare limb of the flap is over tantalum plate, the area will not fill in. For cosmetic reasons, whenever surgically feasible, incisions should be made beyond the hair line.

On reflecting the flap, or on opening the old scar and retracting the wound edges, the scar in the skull defect is separated from surrounding structures

and overlying galea separated away. If intact dura is present, as much scar as possible is resected from its outer surface. If there is no dura present only as much cerebral scar as presents itself in the skull defect is resected. The *x*-rays of the skull are studied at the time of operation and if foreign bodies or depression bone fragments are readily available, they may, at the surgeon's discretion, be searched for and removed.

No attempt has been made in this series to repair dural defects except in the three porencephalic cysts repaired. Previous experimental work[7] indicates that adhesions develop if tantalum foil is placed between the cortex and the arachnoid membrane. Later clinical studies do not substantiate these findings.[8] In a case which will be described later, it became necessary to remove the tantalum plate four and one-half months after its insertion. The plate was covered with a smooth, almost endothelial-like covering internally and externally. As soon as the holding wires were cut, it lifted easily out of its bed. Careful examination revealed no evidence of adhesions internally or externally. It is believed, therefore, that in the presence of a dural defect, a tantalum plate in the bony defect does not encourage the formation of adhesions between it and the injured cortex.

POSTOPERATIVE FLUID COLLECTIONS AND THEIR MANAGEMENT

Before holes were made in the tantalum plates, 80 per cent of cranioplasties were followed by the development of varying amounts of fluid over the plate. This fluid is serosanguineous in nature and is considered to be in part a reaction to the foreign body and in part, slight postoperative hemorrhage. It was noted in several cases in which dural defects existed that the fluid was high in sugar content. The conclusion was, therefore, that this was in part at least spinal fluid and was due to a temporary upset in its absorption. Aspiration of the fluid twice during a period of ten days has usually sufficed to control this complication. No untoward occurrences were encountered from aspiration. The potential danger of infection, however, impels the exercise of the strictest aseptic technic in performing aspiration.

Perforation of the plate by permitting a free flow of fluid facilitates its absorption and since this expedient has been adopted there has been a very obvious diminution in the number of patients developing clinically significant quantities of fluid over the plate. This has been previously reported.[9] The insertion of a rubber drain at operation in the most dependent portion of the wound (removed in twenty hours), and a tight pressure dressing have also materially lessened the formation of fluid over the plate. In borderline cases of scar over the plate where for one reason or another resection of the scar is deemed injudicious, two or three more holes are made in the plate. It is believed that in such cases death of the scar is frequently prevented by permitting the growth of vascular buds through the perforations.

On two occasions the prepared tantalum plate was accidentally dropped during the operation. This entailed a delay while the plate was being resterilized. Such accidents may be precluded by routinely tying the plate to the instrument stand with umbilical tape or heavy black silk until fixation is accomplished.

TECHNICS FOR INSERTION AND FIXATION OF TANTALUM PLATES

Local infiltration with novocaine was employed in every case and no anesthetic difficulties encountered.

Fixation with Screws. (Figs. 5A and 6A.) This is the simplest and most rapid of all the technics in our experience. Where this type of fixation is decided upon, the plate is previously prepared by placing around its periphery six (or more, depending on the size) holes slightly larger than the diameter of the screw that one intends to use. The skull defect is exposed, the bony margins carefully cleared of periosteum,

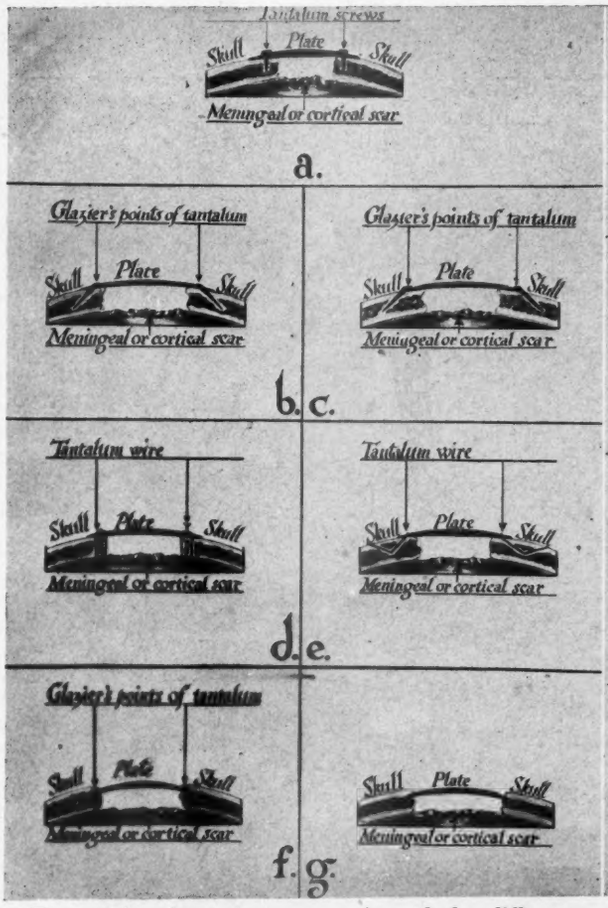


Fig. 5. A schematic cross-section of the different methods used in the insertion and fixation of tantalum plates over skull defects: (*a*) with screws; (*b*) glazier's points through the plate; (*c*) glazier's points over the plate; (*d*) wire through a full thickness of the skull; (*e*) wire through a partial thickness of the skull; (*f*) glazier's points over a counter-sunken plate; (*g*) counter-sinking of the plate without any other fixation.

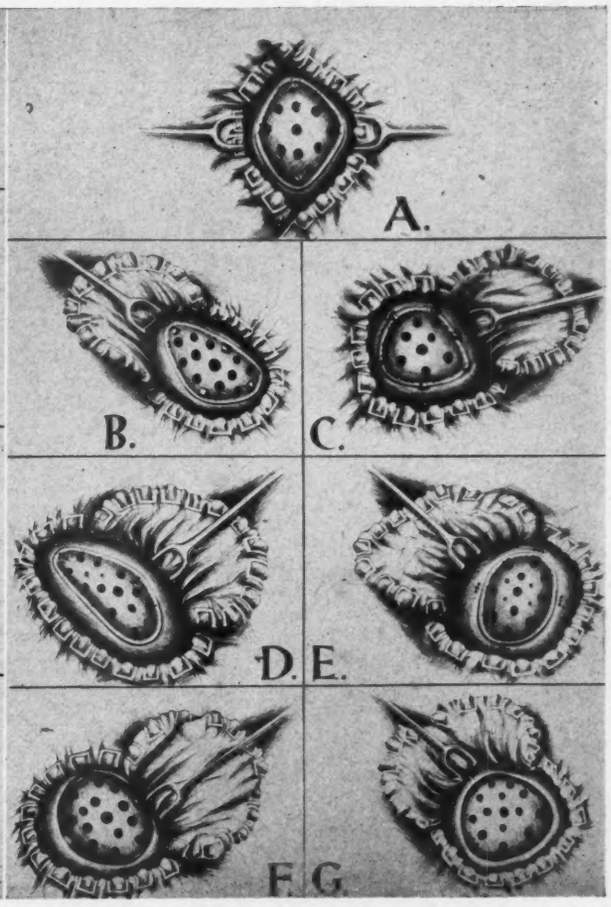
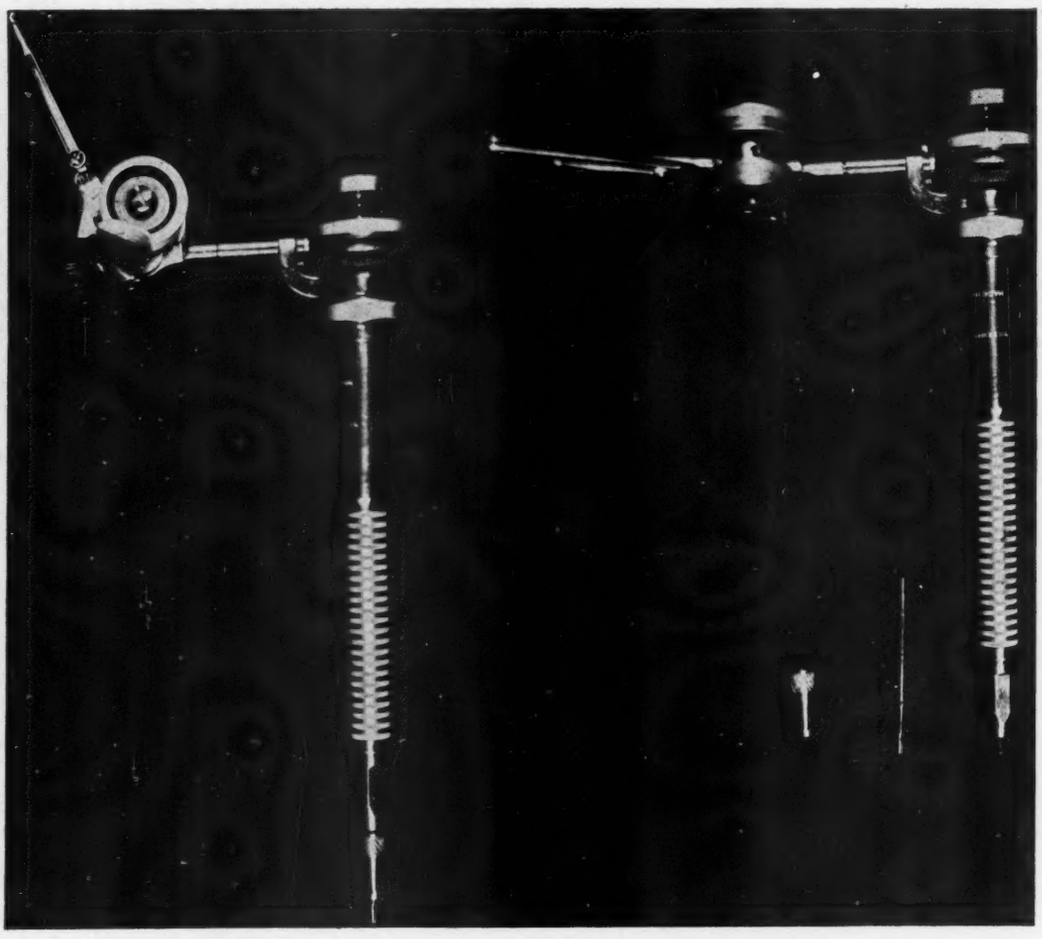


Fig. 6. Artist's sketch of the different methods used in the insertion and fixation of tantalum plates over skull defects: A, with screws; B, glazier's points through the plate; C, glazier's points over the plate; D, wire through a full thickness of the skull; E, wire through a partial thickness of the skull; F, glazier's points over a counter-sunken plate; G, counter-sinking of the plate without any other fixation.

and the plate is fitted to the defect, corresponding to the directional scratches. Minor alterations are then made, if necessary, in the shape of the plate. Through selected perforations in the plate, a number of corresponding holes are drilled through the outer table of the skull. The number of screws needed varies, but the maximum that need be used is six for massive plates; two frequently suffice. The criterion is the solidity of the plate. The plate is then removed and the marking holes are drilled to a depth of 3 mm. A pistol drill handle of the Crutchfield type with a perforator guarded at 3 mm. is a rapid method for making these drill holes. It is, of course, important that the diameter of the drill be slightly smaller than that of the screw. A dental drill with a guard attachment may be employed (Fig. 7) instead of a hand drill. The plate is then replaced accurately over the prepared holes and the screws inserted. A screw holder (Fig. 8B) aids very materially in eliminating the fumbling that goes with the handling of a screw of 3 mm. length.

Certain features of the screw are important. It should be made of tantalum. The head should have a minimum thickness and should be countersunk. The threads should go all the way to the head and the point should be blunted. This technic



A B

FIG. 7.* A simple method of guarding an electrically-driven dental drill from excessive penetration of the skull. The end of the drill handle is cut off and threaded. A small snout made as illustrated is then threaded on the drill handle. A, set assembled; B, set taken apart.

is not properly applicable where the skull is thin, such as in the temporal region. It is highly desirable where only one border of the plate can be fixed, as in plates over the supraciliary ridge where only the upper border of the plate can be fixed.

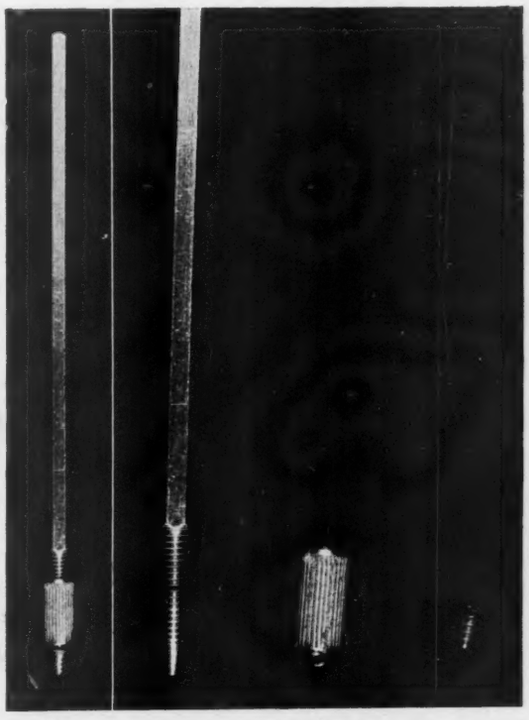
Fixation with Wires. (a) Wires through the entire thickness of the skull (Figs. 5D and 6D): For this method the plate must be prepared by making small holes at 1 cm. intervals along the periphery of the plate with a second, matching set of holes ½ cm. within the outer row. Depending on the size of the plate, from three to six wires are used. Strategic points are then chosen, and with the assistant holding the plate firmly, marking holes in the skull are drilled through the holes in the plate. The plate is then removed. At points opposite the marking holes, the dura is separated from the inner table of the skull. Bleeding is frequently encountered at this point, but is easily controlled with muscle stamps or fibrin foam. With a fine drill, holes are then drilled through the entire thickness of the skull. The accuracy and dispatch of the latter procedure is materially aided, in our experience, by using a fine, electrically driven drill and a Barton drill guide. Where these are not available, the ordinary hand drill with a flat spatula as a guard between the dura and inner table of the skull is used. Here again the guarded dental drill may be employed. Ten cm. lengths of .015 tan-

* Both of these instruments in Figures 7 and 8 were devised under the direction of the author by T/Sgt. William H. Bollinger.

talum wire are then passed through each hole, the end grasped and pulled up. The wire ends are then passed through the chosen holes in the plate,—the end coming through the defect being directed through the inner series of holes and the end coming through the skull passing through the outer series. In this way an exceedingly close apposition of the plate to the skull is obtained. The wire ends are then grasped with a clamp and the clamp rotated, twisting the wire evenly. A little practice is necessary before one knows just how much twisting the wire will take. The ends of the twisted wire are then cut to a length of ½ cm. following which they are bent flat. The sharp ends are lightly tapped with a mallet to smooth them off, or they may be tucked into their respective holes. This method is ideal for the insertion of a plate in a thin portion of the skull.

(b) Wires through a partial thickness of the skull (Figs. 5E and 6E): For this method, the plate must be prepared by making small drill holes in pairs along its periphery ½ cm. apart. At least six sets should be made. The number of wires inserted again depends on the size of the plate. Marking holes are then made through the pairs of holes in the tantalum plate following which the plate is removed. Diagonal drill holes are then made in a direction away from the defect to about half way between the inner and outer table. Another pair of drill holes, 1 cm. peripheral from the first holes, are then made in such a direction as to strike the first holes. Generally four pairs of such holes are sufficient. A 10 cm. length of .025 tantalum wire is then passed through the holes in such a way as to leave the two loose ends coming out of the peripheral ends of the two bony tunnels. The wire ends are then twisted down as above, cut off at a ½ cm. length and the end lightly tapped into one of the holes. This technic is ideal in regions where the skull is thick, and where for one reason or another, screws cannot be used.

Fixation by Glazier's Point of Tantalum.

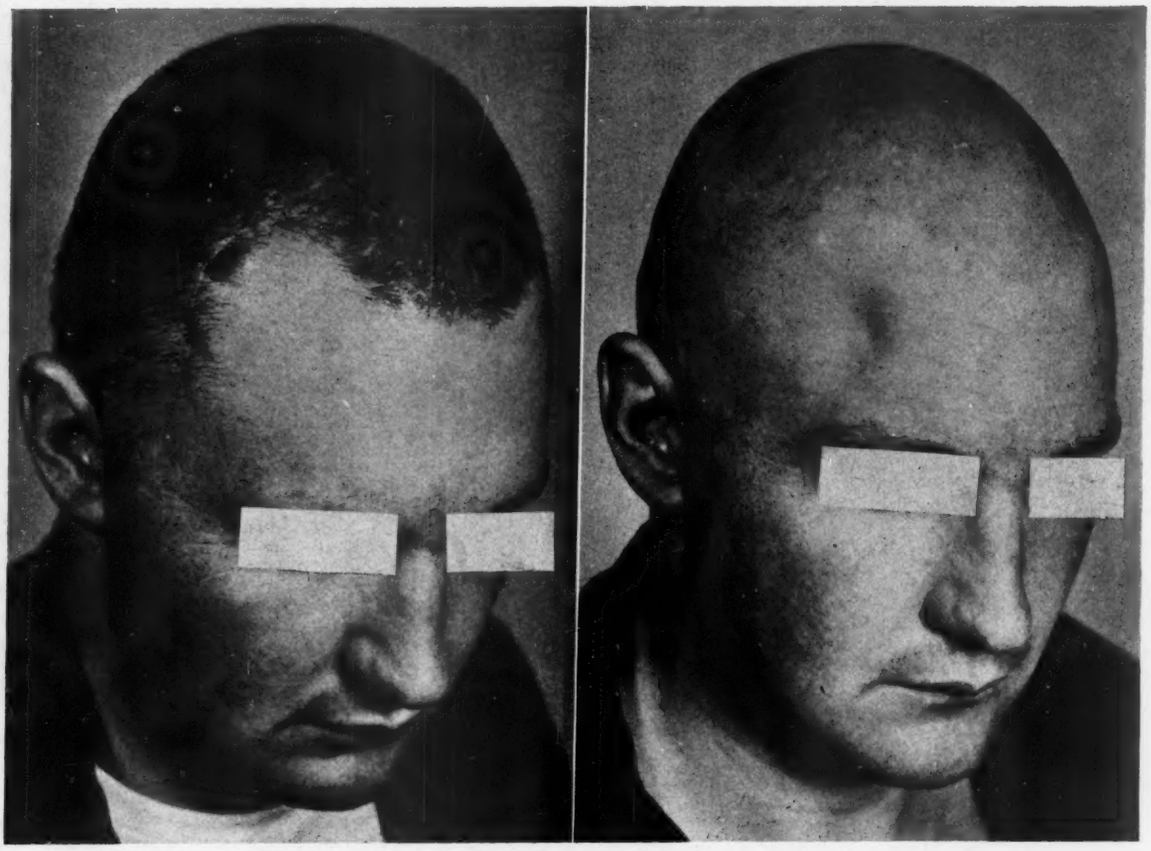


A B

FIG. 8.* A simple screw holder which can be manufactured from the ordinary dental broach holder. A, set assembled; B, set taken apart.

(a) Without countersinking of the plate: 1. With insertion of points through the plate (Figs. 5B and 6B): If this technic is contemplated, five or six slits, 5 mm. long are made near and parallel to the edge of the plate. Glazier's points of tantalum are prepared from trimmings. They should be triangular with a base at least 7 mm. wide and at least 1 cm. long. The assistant holds the plate firmly, and with a small triangular chisel and mallet, a marking hole is made through each slit in the plate. At least four points should be used. The plate is removed and the same chisel used to deepen the holes slightly, the depth varying with the size of the points. These holes should be made at an acute angle and need not go into any appreciable depth. The plate is then reapplied and the glazier's points inserted through the slits, into the holes, and gently tapped in, until they are firmly

* Both of these instruments in Figures 7 and 8 were devised under the direction of the author by T/Sgt. William H. Bollinger.



A B

FIG. 9. The pre- and postoperative pictures of a frontal defect repaired with tantalum plate. The incision in this patient was made behind the hair line. The postoperative picture was taken three weeks following repair. A, postoperative; B, preoperative.

"set." By the time they are "set," if the hole has been correctly made, they are lying flush with the plate.

This method is used where the bone is thin and where for one reason or another, screws or wires are not available. In some centers, it is used in preference to screws or wire. One disadvantage is that a good deal of pounding, however gentle, is necessary in the technic.

2. With insertion of points over the plate (Figs. 5C and 6C): This method is exactly similar to the above except that the points are inserted over not through the plate.

(b) With countersinking of the plate (Figs. 5F and 6F): This technic is exactly the same as (a) except that it is not necessary to make slits in the tantalum plate if it is contemplated. It has been previously described.[2,8] An assistant holds the plate firmly, following which the outline of the plate is cut into the outer table of the skull with a scribner. The plate is then removed, and with a chisel or gouge, and mallet, a ledge is made to correspond with the shape of the plate. The plate is then replaced and three or four glazier's points inserted as above.

This technic is used in the thicker portions of the skull. It is accurate but time consuming and involves also a good deal of hammering on the skull. It is our opinion that the thickness of the tantalum plate is not such that countersinking is necessary.

Fixation by Countersinking Alone. (Figs. 5G and 6G). This method has been previously described and needs no elaboration.[2,10] A ledge is made as described in (3b), a shade smaller than the outline left by the scribner. The previously prepared tantalum plate is then gently teased into the ledge. The spring of the metal against the walls of the ledge is often sufficient

Fig. 10. An illustration of the effective contouring that may be obtained even in large plates by employing the technic of swedging the plate from a plaster cast of the skull defect.

to anchor the plate firmly. This fact is difficult to believe unless the procedure is tried. If the plate is not firm, a few glazier's points are inserted.

Again, this technic involves gentle but comparatively prolonged hammering. It can be employed anywhere in the skull. It is time consuming but accurate.

Fig. 11. Lateral *x*-ray view of two large tantalum plates to illustrate the fact that should an encephalogram be necessary in the future, important details will be hidden by the radiopaque tantalum plate.

RESULTS

In this series there were no postoperative infections or deaths. Up to the present, all plates have remained firm. With the current technic, which includes perforation of the plate and drainage for twenty-four hours, the development of fluid overlying the plate has been reduced to a minimum. In only one instance was it necessary to remove the plate because of the persistent accumulation of fluid. This was one of the earlier cases of this series in which the plate was not perforated.

Satisfactory cosmetic results were obtained in each case comparable to that illustrated in Figures 9 and 10. In four cases, thin scalp scars broke down over the tantalum plate. Of these, three were readily repaired by sliding scalp flaps. The fourth proved too large to be dealt with in this manner and required a full thickness skin graft. This was successful.

In those cases in which tenderness of the scar existed prior to cranioplasty, relief was afforded by operation. Two patients who complained of feelings of insecurity because of the defect in the skull were notably relieved following cranioplasty.

A not infrequent complaint among patients with tantalum plates is, that in very cold weather an uncomfortable sensation of cold is felt at the site of the repair. There have been no corresponding complaints in hot weather.

One objection that has been raised to the use of metallic plates (as opposed to plastic materials) in cranioplasty is that, if pneumoencephalography should be in-

dicated at a later date, important details may be obscured. (Fig. 11.)

INFECTIONS

In this series of 154 cases of compound fracture of the skull, 126 appeared to have had adequate débridement within three days of injury, and of these only one wound became infected (an instance of brain abscess, later evacuated and healed). Seven patients were not subjected to débridement at all, and of these four (57 per cent) became infected. Nine cases were considered to have been inadequately débrided within the first three days as determined by the demonstrable presence of foreign bodies* and of these six (67 per cent) developed infections. Table IV sets forth the relations between the time and apparent adequacy of débridement following injury and the incidence of infection.

In twelve cases débridement for one reason or another was postponed beyond three days after the injury. Among these, infection supervened twice, one an instance of osteomyelitis of the vault, the other an instance of extradural abscess. It is of interest that the patient in whom débridement was longest postponed—fourteen days—did not develop an infection. The tabular analysis (Table IV) indicates that while there is in general a significant direct relationship between the time period within which débridement is undertaken and the development of infection, this relationship is not necessarily decisive. Without doubt, the advent of chemotherapy has given to the surgeon a considerable latitude within which débridement is considered mandatory.

In three cases which appeared to have been adequately débrided, osteomyelitis of the skull complicated by extradural abscess developed. The operative record in each case disclosed that free fascial

* A difficulty presents in any attempt to decide whether a case was "adequately" or "inadequately" débrided in the echelons of combat or communicating zones. It is entirely possible that in some cases devitalized and potentially infected soft tissues were left *in situ* and that the growth of bacteria was inhibited by the preoperative and postoperative use of sulfur drugs and penicillin. There is obviously no way of identifying the "adequacy" of débridement in such cases. Similarly, results alone cannot fairly be made the measure of "adequacy" of débridement since infections may occur under some conditions in patients quite properly débrided from the surgical standpoint. It seems safe, however, to employ the term "inadequate" when roentgenographic and surgical findings permit the inference that débridement was indeed incomplete.

TABLE IV

THE RELATIONSHIP BETWEEN THE ADEQUACY AND TIME OF DÉBRIDEMENT FOLLOWING INJURY, THE PRESENCE OR ABSENCE OF DURAL TRANSPLANTS AND THE ONSET OF INFECTION

Type of Infection	Adequate Débridement Soon after Injury (less than 3 days)	Inadequate Débridement Soon after Injury (less than 3 days)	Adequate Débridement Late after Injury (4 days to 14 days)	No Débridement	Free Fascia Lata Grafts Inserted at Time of Débridement	Free Temporal Fascia Graft Inserted at Time of Débridement	Sliding Dural Grafts Inserted at Time of Débridement	Tantalum Foil Inserted at Time of Débridement
Simple scalp infection	0	2	0	0	0	0	0	0
Osteomyelitis of skull	0	1	1	2	0	0	0	0
Extradural abscess with osteomyelitis of skull	0	1	1	1	2	1	0	0
Brain abscess	1	2	0	1	0	0	0	0
No infection	125	3	10	3	6	3	2	2

grafts had been employed to close the dural defect at the original débridement. Two of the grafts were of fascia lata and the third was a free temporal fascia graft. All three sloughed out while under our care. Each was subjected to a new débridement and plastic repair of the scalp with primary closure. In these, as in all infected and potentially infected cases of this series, penicillin was administered intramuscularly in 110,000 unit doses each day for seven days beginning on the day of operation. The value of penicillin in the treatment of osteomyelitis of the skull has already been described.[11] Tantalum plates were inserted approximately one month after the scalp closure. In each case healing proceeded without untoward occurrence.

The data at hand suggest a considerable likelihood that infection will develop if free grafts are employed to accomplish dural closure at the time of first débridement. Even though full allowance be made for the fact of their autogenicity, such grafts, inasmuch as they possess no blood supply, constitute in effect foreign bodies. As such, they favor the growth of bacterial organisms which might well succumb to immunologic and chemotherapeutic control were there no foreign body present. Acknowledgment must be made of the general soundness of the surgical principle that dictates anatomical closure of tissues. Nevertheless, the necessity of closing the dura seems to have been overemphasized. It does not appear defensible to give the principle of layer-by-layer closure precedence over the equally well established surgical principle of scrupulous avoidance of foreign bodies in potentially infected wounds.

In addition to the three cases referred to above, we encountered seven other instances of osteomyelitis of the skull, three of which were also complicated by extradural abscess. (Table v.) In each of these cases, treatment consisted of wide resection of the involved bone and the maintenance of open drainage until the area became cicatrized. Approximately a month later the scar was resected and a tantalum plate inserted. In all, healing proceeded without complication. In cases of chronic osteomyelitis of the skull, as in the fresh cases of open craniocerebral wounds, the advent of chemotherapy has made possible an active

TABLE V

THE RELATIONSHIP OF THE DEGREE OF BRAIN INJURY TO THE ONSET OF SEIZURES AND OF INFECTION

Degree of Craniocerebral Injury	Seizures Immediately Following Cranioplasty without Late Recurrence	Seizures Immediately Following Cranioplasty with Late Recurrence	Seizures before Cranioplasty without Postoperative Recurrence	Late Onset of Seizures Following Cranioplasty	Simple Scalp Infection	Brain Abscess	Osteomyelitis of the Skull	Extradural Abscess with Osteomyelitis
Without dural or brain laceration.....	0	0	0	0	2	0	1	5
With dural laceration but without brain injury.....	2 generalized	0	0	0	0	0	1	1
With dural and brain laceration.	1 Jacksonian	5 Jacksonian 2 generalized	6 Jacksonian 1 generalized	8 Jacksonian 1 generalized	0	3	1	0
Findings at initial débridement unknown	1 Jacksonian 2 generalized	1 Jacksonian 1 generalized	0	4 generalized	0	1	1	0

attack on a surgical problem of a difficult sort, which, until very recently, demanded caution and extreme conservatism.

In two of our patients, infection was confined to the scalp. Moist dressings were employed for four weeks without salutary effect. The indolent area was then resected and the scalp closed anatomically with silk. The wounds in each case healed without drainage. Approximately one month later tantalum plates were inserted. The postoperative course in these patients was uneventful.

In four instances, compound fractures of the vault were complicated by the development of brain abscess. Three of these were healed by surgical marsupialization in combination with chemotherapy. In each case tantalum plates were inserted approximately three months after the completion of epithelialization. The fourth case was admitted in extremis. Some seven weeks prior to admission he had sustained a severe bifrontal compound comminuted fracture with massive damage to frontal lobe tissue. The wound had not been débrided. Shortly following admission, open drainage of the abscess was instituted but death occurred on the third postoperative day. Autopsy disclosed a second brain abscess 4 cm. lateral to that which had been surgically drained.

INTRACRANIAL FOREIGN BODIES

Among the 170 cases of this series foreign bodies were removed from thirty eight (22.3 per cent). Approximately four-fifths of these were bony and with one exception (a piece of helmet liner) the remainder were metallic fragments.

The following were considered indications for the removal of foreign bodies (Table III): (1) The presence in infected areas of metallic fragments, sequestra or indriven bone fragments; (2) the presence of foreign bodies considered as the likely cause of or favoring the persistence of neurological dysfunctions; and (3) the relative accessibility, without entailing undue cerebral damage of foreign bodies in the operative fields of patients undergoing cranioplasty.

It was considered unwarranted to attempt the removal of a foreign body deeply embedded in the brain, not regarded as responsible for neurologic disturbances or likely to produce infection.

In fifteen instances operation was performed chiefly from the necessity of removing fragments from the region of the skull defect. In each of these tantalum cranioplasty was carried out at the same operation. In no case did untoward complications appear.

From twenty-three patients subjected to operation chiefly for cranioplasty, metallic and bony fragments were incidentally removed.

It is difficult to determine whether in those cases presenting focal neurological disturbances the removal of foreign bodies was a significant factor in their subsequent clinical improvement. Our impression is that valid estimates along this line could not be drawn for the reason that in most cases considerable time elapsed between the surgical procedure and the first appearance of improvement,—a period during which it is conceivable that concurrent reparative processes and other factors (e.g., vicarious functioning and re-education) were at work.

In only one case did it become necessary to apprehend the foreign body through a bone flap away from the site at which the missile penetrated the skull. In this patient, a large metallic fragment had lodged in the anterior vermis just under the tentorium. (Fig. 12.) Incapacitating dizziness was the patient's most conspicuous neurological symptom. A small occipital bone flap was reflected and, through an incision in the tentorium, the fragment was removed, affording prompt relief from dizziness.

CONVULSIVE SEIZURES

For raw statistical purposes, all patients who displayed the phenomenon of recurring explosions of tonic or clonic contractions, whether mild, moderate or severe and

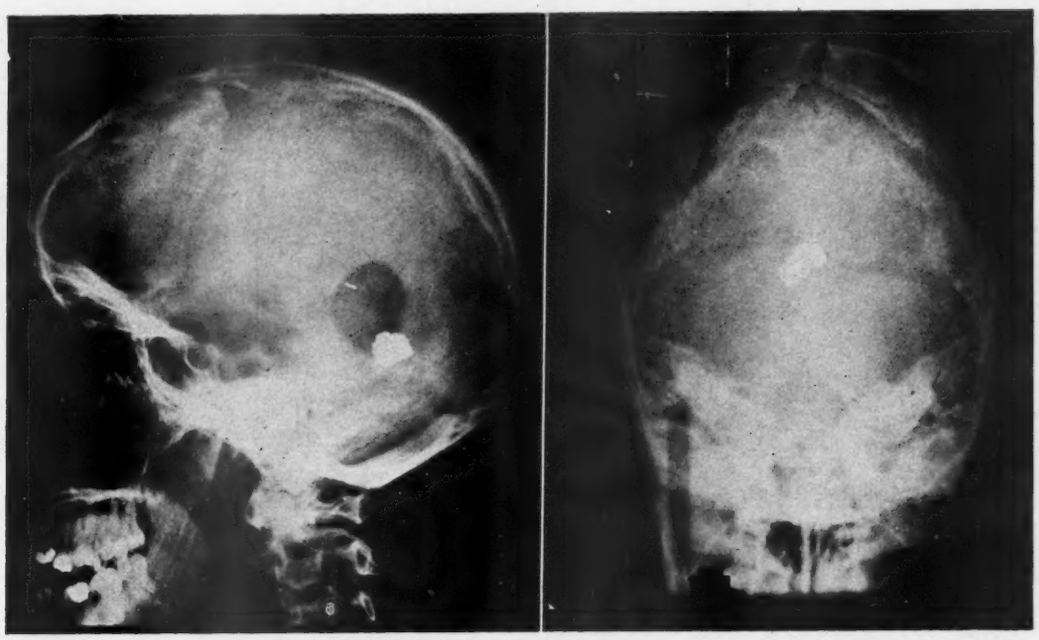


Fig. 12. Roentgenograms of the skull revealing a sub-tentorial shell fragment, the removal of which necessitated an approach, (away from the wound of entrance) through an occipital bone flap, and through an incision in the tentorium cerebelli. Immediately following operation, there was almost complete recovery from previous incapacitating dizziness.

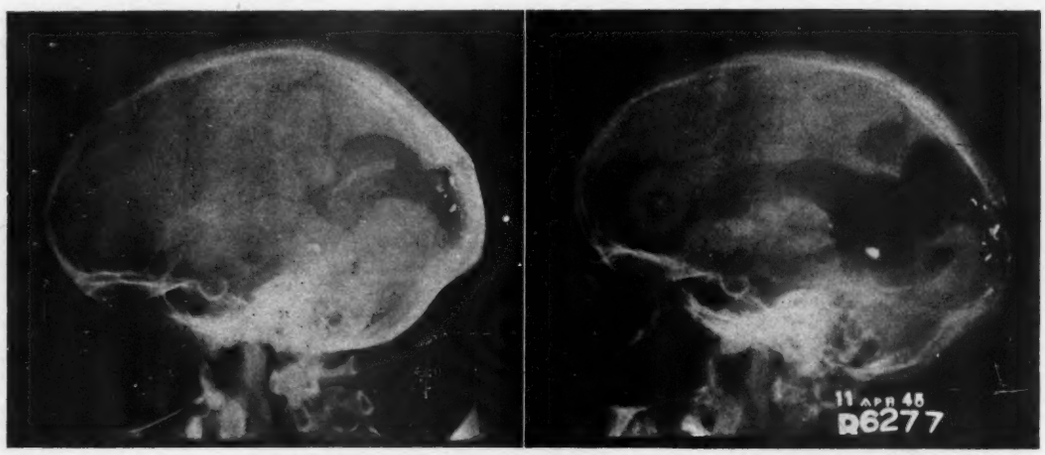
whether or not attended by loss of consciousness were included in the convulsive seizure group. Thirty-five patients (20.6 per cent of the series) fell into this group. (Table v.)

Our present figures must be regarded as tentative and it is likely that they will increase as the follow-up period progresses during the next decade. Our oldest cases have been followed for a little over two years and the most recent for but two months. Before being separated from military service, all our patients who have had serious craniocerebral trauma are instructed to report upon seizures when and if they occur. It is safe to assume that not all patients may be relied upon to so report. The inevitable consequence of this will be that statistical data, properly cleared, will undershoot the mark, and some allowance will, therefore, have to be made for this when comparative studies on post-traumatic epilepsy appear in the literature.

In twenty-two of our patients the pattern of attack chiefly observed was of the jacksonian variety. In thirteen others the most characteristic attack was of the "grand mal" type. We have regarded the differences between jacksonian and grand mal patterns as merely clinical description indicative only of the probable locus of an epileptogenous "firing point" rather than as significant for etiologic, pathologic or other qualitative differences.[12,13] That more than one "firing point" may exist in any given case seems a substantial concept.

In seven cases, convulsive seizures had developed before surgical repair was carried out at this hospital; in fifteen the first (known) attack developed within two weeks of operation; and in thirteen seizures did not make their appearance until five to fourteen months after cranioplasty. Each of these three groups will be separately considered from the gross pathologic and therapeutic standpoints. (Table v.)

All seven patients whose seizures were established prior to cranioplasty had meningocerebral scars, the result of laceration of the dura and adjacent brain. Porencephalic cysts were present in three of these, among which was one patient in whom a piece of tantalum foil had been used at the original débridement to bridge a large dural defect. The tantalum had



A B

FIG. 13. A, an illustration of the use of tantalum foil as a dural substitute. This soldier had a very severe meningocerebral laceration. The wound was débrided overseas and the tantalum foil inserted to act as a dural substitute. At the time of cranioplasty the tantalum foil was found buried in a mass of heavy meningocerebral scar. B, a lateral pneumoencephalogram of the same patient described in A. The large porencephalic cyst was uncapped and the meningocerebral scar resected. No seizures were reported postoperatively (thirteen months).

become fragmented (Fig. 12) and was found buried in the cerebral scar overlying the cyst. All of these patients were medicated with barbiturates, beginning on the day of operation and continuing for a period of approximately eight weeks thereafter. In all but one of these patients no recurrence of seizure was reported. In this patient a seizure occurred during the fifth postoperative month. Phenobarbital was resumed and up to the present no seizures have been reported. Cranioplastic repair was carried out on these seven patients. The porencephalic cysts were uncapped incidental to cranioplasty and their corresponding dural defects were closed with fascia lata grafts. Among the remaining four patients, two presented intact duras (their defects having been repaired at the time of the original débridement) and two had defect of the dura. In each of the latter cases, the cortical scars were resected but no attempt was made to repair the dura.

There were fifteen patients whose seizures first appeared within two weeks of cranioplasty. In six of these only one to two seizures occurred and, up to the present, no recurrences have been reported. Of this group of six, four patients revealed an intact dura at the cranioplastic procedure. The other two presented dural defects and in one of these a cerebral scar of sufficient extent and density to warrant excision was exposed. The remaining nine patients continued to have seizures for several months, and three of them still report occasional attacks. At operation two of these presented dural defects and seven appeared to have an intact dura. In the former the cerebral scars were resected but no dural repair was attempted; in the latter no surgical treatment other than repair of the cranial defect was carried out. Barbiturates have been regularly prescribed for those patients with recurrent attacks.

There were thirteen patients whose first seizures came late after the repair of the skull defect. The earliest of these appeared five months and the latest fourteen months following cranioplasty. Among these, ten had had, at the time of injury, lacerations of the dura which had been repaired at débridement. The remaining three presented the late evidences of unrepaired dural defects and meningocerebral scars. In the former, nothing surgical was done other than the repair of skull defects; in the latter, the meningocerebral scar was resected but no attempt at dural repair was made. As in the previous

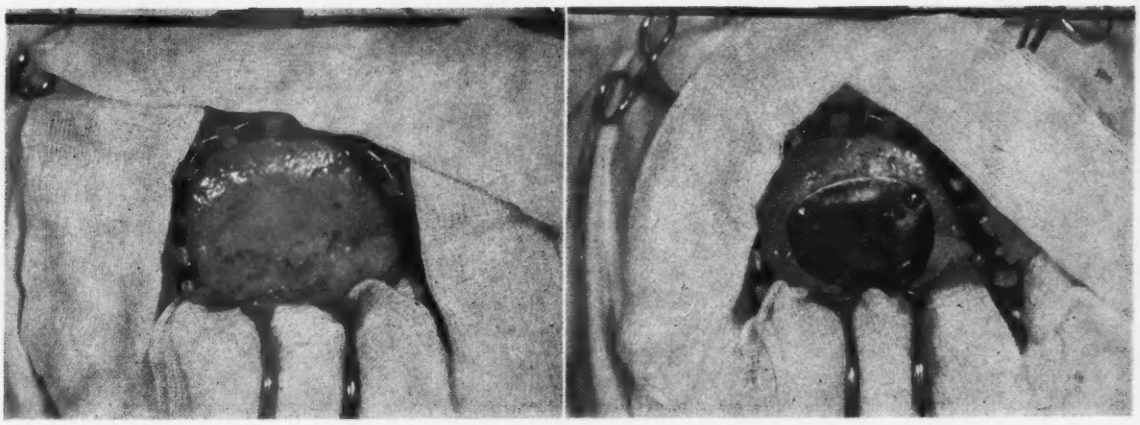


FIG. 14. Color photographs of a skull defect with an intact but somewhat scarred dura before and after the insertion and fixation of a tantalum plate using screws.

group, all of these seizures have been controlled by the use of barbiturates.

In reviewing the series as a whole there is general agreement with the experiences of Wagstaffe, Penfield and Erickson,[15] and Penfield,[16] that the incidence of seizures in patients in whom the dura and brain were lacerated at the time of injury is higher than in those in whom these structures are not so damaged. Other writers have reported a higher incidence of post-traumatic epilepsy (Schürer-Waldheim[17] 25 per cent, Baumm[18] 44 per cent). In our series it happens that seizures were not recorded in patients in whom, so far as could be judged, the dura and the brain had not been lacerated; on the other hand in all patients with convulsions there was evidence that the dura and brain had been lacerated at the time of injury. The significance of these figures is somewhat diminished when it is recognized that the vast majority of patients in this series, for the very obvious reason that they required cranioplasty must have had lacerations of the meninges and brain. Similarly, a lacerated cortex might well have been hidden from view by an intact dura. That 20 per cent of our patients developed seizures, all of whom lacerations of the dura and brain is somewhat offset by the complementary observation that in the great bulk of our cases without convulsions the dura and brain were lacerated.

Among the 154 cases of compound fractures of the skull in this series there were forty-one patients in whom the dura was not repaired at the time of débridement and in whom the skull defect was occupied by galeal and meningocerebral scar. Of these eleven (25 per cent) developed seizures at one time or another. Among the remaining 113 patients there were twenty-three (21 per cent) in whom the dura was repaired at the time of débridement and who developed seizures. There is, therefore, in this series no evidence that repair of the dura mater at the time of original débridement is a significant factor in the prevention of post-traumatic epilepsy. Furthermore as seen from the tabular analysis (Table VI) there is little or no evidence to indicate that repair of the dura some months following injury precludes the onset of seizures.

TABLE VI

ANALYSIS OF THE INFLUENCE OF DURAL REPAIR AT THE TIME OF CRANIOPLASTY ON THE DEVELOPMENT OF SEIZURES

Condition of Dura	Onset of Seizures Immediately Post-operative without Late Recurrence	Onset of Seizures Immediately Post-operative with Late Recurrence	Late Onset of Seizures Following Repair	No Seizures
Dura intact....	4	8	10	91
Dural defect not repaired at cranioplasty..	1	2	3	35
Total.....	5	10	13	126

In this group of cases resection of meningocerebral scar was carried out only where the scar presented itself in the skull defect and in the three porencephalic cysts already referred to. It does not appear indicated routinely to resect every meningocerebral scar encountered at the time of cranioplasty. It seems preferable to resect this scar only when it is easily available and when its removal is not likely to further impair cerebral function. If the scar is not readily accessible and if seizures have not occurred, cranioplasty alone appears indicated; if clinically indicated, resection of the meningocerebral scar can be performed at a later date.

There is no evidence from our observations that tantalum cranioplasty has an influence on the development of post-traumatic seizures.

NEUROLOGICAL SEQUELAE (OTHER THAN CONVULSIONS)

Among the 170 patients, fifty-one presented no clinical neurological disturbances at the time they came under our care, five weeks to five months following injury.

The remaining 119 patients showed various aberrations of both focal and general character. No attempt has been made to itemize all disturbances encountered in each patient. The tabular analysis (Table 1) confines itself to a consideration of the most conspicuous neurological sign or symptom encountered in a given patient. By far, the commonest disturbance was hemiplegia of which there were thirty-six cases. Closely allied to these and differing from them in degree only were the thirty-three patients with hemiparesis. As would be expected from anatomical considerations, 78 per cent of these were subtended by injuries of the temporoparietal regions of the vault. The second commonest neurological sequel was the post-traumatic syndrome, the separate symptoms of which are listed elsewhere in this communication. There were twenty-seven such cases. The third commonest disturbance was aphasia of which there were twenty-one instances. All of these were associated with hemiplegia of varying degree. Eleven patients presented hemianopsia. The remaining disturbances were few in number and of varied character. (Table 1.)

In forty-three instances differential diagnosis was not resolvable by clinical study alone, and in these cases pneumoencephalography was employed. It was incidental to this procedure that three porencephalic cysts were disclosed. It is clear that the mode of operation in these three patients was very appreciably influenced by the information obtained from the air studies.

Among the hemiplegic and aphasic there was in general a tendency toward spontaneous improvement. All but one of the hemiplegics improved sufficiently to walk unaided. The vast majority of them were ultimately able to dispense with a cane. Similarly all the aphasic patients except one regained a sufficient vocabulary to be able to communicate their common needs. In many, a near-normal speech function was regained. The single patient who did not appear to improve during a period of observation of eighteen months had profound destruction of the left temporoparietal lobe.

It cannot be asserted with any certainty that the surgical procedures employed in these patients, which included removal of foreign bodies, resection of meningocerebral scars and repair of skull defects exerted any salutary effect on the recorded clinical course. Measures carried out over a sufficient period of time directed at the general psychological improvement of the patient including physical therapy, speech training, reconditioning and occupational therapy are all important determinants of the end result.

POSTCEREBRAL CONCUSSION SYNDROME

This syndrome, otherwise known as the post-traumatic syndrome and the syndrome of the trephined, is commonly considered to include headaches, dizziness, insomnia, asthenia, fatigability, nausea, deficiency of attention and tinnitus. Only three of the twenty-seven patients complaining of these symptoms presented focal neurological signs,—two had hemiparesis and one had homonymous hemianopsia. With three exceptions the patients who developed the syndrome were unconscious for twenty-four hours or less; ten were unconscious for less than three hours. This analysis points to the fact that the post-traumatic syndrome is, in general, most likely to occur in the milder group of craniocerebral injuries. It is of interest to note that there was no correlation between the size of the bone defect and onset or severity of the post-traumatic syndrome.

Of the twenty-seven patients complaining of these symptoms, twenty-three had complete relief, two had partial relief and two had no change in their symptoms following cranioplasty.

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Acute traumatic cerebral compression is due chiefly to hemorrhage from a fracture involving the squamous plate of the temporal bone. In 90 per cent of the cases the bleeding occurs from the anterior branch of the middle meningeal artery; in 10 per cent from the posterior branch.

From "Principles and Practice of Surgery" by W. Wayne Babcock (Lea & Febiger).

PAINFUL INJURIES OF NERVES AND THEIR SURGICAL TREATMENT*

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INTEREST was first focused on the elusive problems of pain after wounds of the peripheral nerves by the classical description of Mitchell, Morehouse, and Keen[35] in a book based on their experience with these distressing injuries during the war between the States. After such a promising early start, it is surprising that more was not found out about these lesions during the periods of peace and recurrent wars which led up to the recent conflict. During and after the first World War the pioneer work of Leriche[25] has been a constant stimulus. The solution of how to relieve most of these sufferers by neurosurgical intervention has evolved gradually and finally been put on a fairly satisfactory basis by the combined work of American and British military surgeons during the war just finished. With the great number of amputations and injuries of peripheral nerves which have reached our base hospitals from overseas, these sources of persistent pain are certain to be a major reconstruction problem for years to come.

UNDERLYING PATHOLOGICAL FACTORS

The common injuries which may lead to persistent pain are amputations and partial or complete wounds of the peripheral nerve trunks. Concomitant injury of a large artery may also occur, but as this complication is not present in the majority of cases it cannot play any important rôle. Faulty regeneration of injured nerves, sepsis, and resultant formation of scar tissue appear to constitute the underlying factors which give rise to painful stimuli, although some further factor is necessary to explain the onset of burning pain in the hand or foot which sometimes develops within a few hours after the wound. Wilfred Trotter[45] in his classical essay on "The Insulation of the Nervous System" pointed out that all regenerating sensory axones "resemble pain fibres in a lack of complete insulation. It is probable, therefore, that imperfect insulation tends to render all fibres less sensitive than normal, but more apt . . . to respond in an exaggerated explosive way." Recent determinations of the threshold for "burning" as contrasted with "pricking" pain performed by Bigelow, Harrison, Goodell, and Wolff[3] have demonstrated that the slowly conducting, poorly myelinated "C" fibers carry these disagreeable forms of sensation. The "paradoxical pain" of the peripheral neuropathies is the expression of a defect in the nerve in which the threshold for "burning pain" is depressed, so that ordinary innocuous stimuli are perceived as painful, whereas the threshold for "pricking pain" in the larger myelinated fibers is elevated. Another theory based on partial injury of sensory axones has been put forward by Foerster (Bumke and Foerster[5]). This assumes that the larger myelinated sensory fibers which enter the posterior columns of the spinal cord exercise an inhibitor action on the smaller pain fibers, so that an exaggerated painful response (hyperpathia) may result after a partial nerve injury in which a majority of the former axones have been destroyed.

Another likely factor in the production of pain is anoxia, either from local scarring or from widespread vasoconstriction. In recent

* From the U. S. Naval Hospital, St. Albans, N. Y., and the Neurosurgical Service of the Massachusetts General Hospital, Boston. This article has been released for publication by the Division of Publications of the Bureau of Medicine and Surgery of the United States Navy. The opinions and views set forth are those of the writer and are not to be construed as reflecting the policies of the Navy Department.

experiments Lorente de Nó[29] has shown that a nerve made anoxic fires off repetitive stimuli, which suggests that impaired circulation may be a fundamental source of painful stimulation. Still another possible explanation is an accumulation of painful metabolites in the neuroma, and the failure of the impaired circulation to wash them away. Neuromas combine the two essentials of naked nerve endings in a mass of poorly vascularized scar tissue. Amputations and wounds of nerves near the periphery of a limb are most likely to set up persistent painful states because of the greater number of nerve endings and the greater intensity of the vasomotor discharge in these areas. The incidence of painful complications is particularly high in emotionally unstable individuals with superimposed vasomotor disorders.

In addition to the possible rôles of vasospasm and local ischemia in the production of these painful states, Doupe, Cullen, and Chance[11] have suggested another factor associated with overactivity of the sympathetic nervous system. They ascribe the peculiar qualities of causalgic pain to direct cross stimulation of sensory fibers by efferent sympathetic impulses at the point where the nerve trunk is injured, rather than to the indirect action of the vasoconstrictor response which they also produce. This theory deserves serious consideration, as in certain stages of the evolution of many of these painful syndromes there may be an actual vasodilatation. Doupe and his co-workers have cited most convincing evidence for this activation of sensory fibers by sympathetic impulses. Their theory furnishes an explanation not only for the increase in pain which so characteristically takes place in a cold environment, but also for that occurring during any form of emotional excitement, cutaneous stimulation, and, in some extreme instances, during everyday visual and auditory stimuli. Burning pain in causalgia and in certain other conditions occurs in direct relationship to the tonic vasomotor, sudomotor, and pilomotor discharge over the sympathetic efferent pathways. It is reduced in a quiet, stable environment and during sleep, when the tonic hypothalamic discharge is greatly diminished. There is no valid evidence that the sympathetic system plays any direct rôle in the central conduction of the painful stimuli.

As further corroboration of this theory of sympathetic activation of sensory fibers, it has been shown by Katz and Schmitt[24] that under certain circumstances efferent nerve impulses can alter the excitability of adjacent sensory axones. Recently Granit, Leksell, and Skoglund[15] have given direct experimental proof of such cross-stimulation between motor and sensory fibers at a point of nerve injury by recording with the cathode ray oscillograph an afferent discharge from the sensory root which takes place when the motor root is stimulated. They conclude that the small, poorly myelinated pain axones of the C-group should be especially susceptible to "fiber interaction," and that this is a simple explanation for some of the symptoms of causalgia. The theory of Doupe and his co-workers assumes that the activating impulses come from the sympathetic vasomotor, pilomotor and sudomotor discharge, which is always increased by cold or emotional excitement.

TYPES OF PAIN

Painful Neuromas. End bulb neuromas, which can often be palpated in an amputation stump or scar over an injured nerve, can produce exquisite local tenderness and, in addition, cause ill defined disagreeable sensations over wide areas. Although the local tenderness may be relieved by resection of the end bulb and effective measures to prevent its reformation, various forms of pain may persist—phantom sensations in the missing extremity, burning hyperesthesia, deep aching sensations with central radiation, and at times crises of lancinating pain. Why most neuromas should be painless and others the cause of long-lasting torture is quite unknown. This cannot be explained entirely on the basis of

any idiosyncrasy on the part of the individual patient (such as a low threshold for pain), because in certain individuals with multiple nerve injuries or amputations only a single neuroma will become painful (Livingston[28]). Why is removing the pain-producing neuroma so seldom successful? A new neuroma may form, but sometimes the pain is not even temporarily relieved or recurs sooner than the peculiar end bulb can be reproduced. This and the fact that more proximal crushing or chemical destruction by infiltrating the nerve trunk with alcohol fails to give relief has forced investigators to predicate a central extension of the pain mechanism. Mitchell, Morehouse, and Keen[35] described an ascending neuritis, but numerous examinations of sections of nerves removed during therapeutic neurectomies have failed to show evidence of any histologic alteration. It is, therefore, far more likely that the central disturbance is due to abnormal spinal reflex or cortical activity, as has been suggested by Livingston[28] and by Doupe et al.[11]

Causalgia. The classical causalgic syndrome, described by Mitchell, Morehouse, and Keen,[35] is most often seen after partial injuries of the ulnar, median, and sciatic nerves. (Fig. 1B.) While subsequent sepsis and excessive scar tissue reaction may at times constitute predisposing factors, the characteristic pain often appears within a few minutes or hours of the receipt of the wound. (Table III.) A peculiar burning and tingling hyperpathia* involves the hand or foot and is most pronounced in the digits, palm of the hand, or sole of the foot. With complete immobility from pain, the skin soon becomes shiny and glossy smooth, at times scaly and discolored (Fig. 1A), with tapering fingers and long curved nails. The painful area is frequently not restricted to the area of sensory defect, but this is often difficult to ascertain because no accurate neurological examination is possible during the acute phase. Sudomotor and vasomotor disturbances are the rule. According to de Takáts,[43] there is invariably a vasodilatation, which he ascribes to the vasodilator action of the posterior root fibers (Bayliss[2]), and he goes so far as to state that this response is a point in the differential diagnosis between these painful states and hysterical paralysis in which the hand is generally cool. In Mayfield and Devine's[33] carefully observed series they found three patients with cold and nine with hot extremities, whereas in the author's eleven Naval and Marine Corps patients who were hospitalized at a somewhat later date after wounding the extremities were always considerably cooler than normal. It is important in this connection to remember that the sympathetic vasomotor nerves invariably serve as vasodilators to muscle and also carry a certain proportion of dilator fibers to the skin, in addition to supplying the entire innervation of the sweat glands.[53] For this reason excessive sympathetic activity in emotional states results in profuse sweating of the palms and soles, and at times warm but more often abnormally cool extremities. While de Takáts[43] has shown by oscillometric tracings that the vasodilator response is unilateral, the vasoconstriction and abnormal sweating usually involve the other extremities, although possibly to a lesser degree. It is quite possible that cutaneous vasodilatation is the characteristic condition in the early phase of causalgia, but after a time at least the opposite is frequently true. Everyone who has studied the condition has been impressed by the profuse sweating of the involved hand or foot, but nervous sweating of the hands and feet is a common phenomenon in wounded men, especially when pain is a prominent feature.

In the typical severe forms of causalgia the cutaneous hyperesthesia may become so intense that the patient cannot bear contact with clothing or even draughts of air. The extremity is kept constantly

* The term "hyperpathia" is used to connote widespread burning, throbbing, or tingling set up by mild cutaneous stimuli and spreading over a wide area. It is thus an exaggerated form of the hyperesthesia seen in the area of a regenerating nerve.

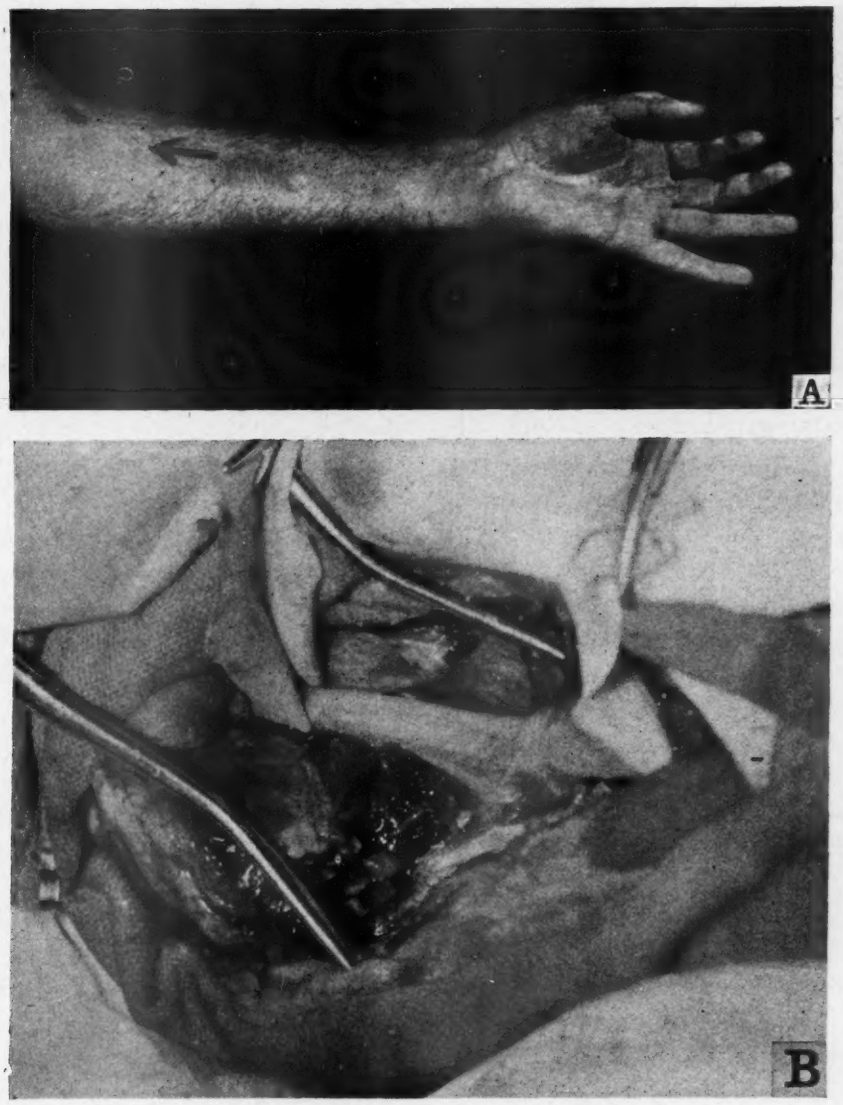

Fig. 1. Median nerve causalgia (Case 22). A, trophic changes in area of hand supplied by median nerve. The arrow marks the penetrating gunshot wound in the upper forearm. B, lateral scarring and adhesions of median are seen between points where nerve is elevated by rubber bands. The superficial head of the pronator radii teres muscle has been divided and spread by self-retaining retractor. Although neurolysis failed to benefit, all symptoms were relieved by subsequent sympathectomy.

protected and immobile, and must often be wrapped in a cloth or moistened with lukewarm or cold water. The patient becomes more and more a recluse and seeks to seclude himself from the noises and stimuli of an open ward. He cannot listen to tense or annoying radio programs or sit through an exciting movie. Any disagreeable stimulus, such as tickling or scratching the skin, or a hypodermic injection in any part of the body, produces unbearable pain in the affected extremity.

It has often been claimed that the condition is most likely to result after nerve wounds in which there is associated sepsis or arterial injury. The latter is certainly not an important feature, and most of the recently reported cases have not been preceded by major wound sepsis. Nevertheless, as healing following gunshot wounds has improved with better surgery since the time of the Civil War, the incidence of major causalgia appears to have steadily decreased. The outstanding reports in the

recent war have been presented by Doupe et al.,[11] seven cases from a large hospital for nerve injuries in England; Mayfield and Devine,[33] fifteen cases among 737 peripheral nerve injuries at the Percy Jones General Hospital; and Speigel and Milowsky,[40] seven cases among 275 soldiers at another U. S. Army Hospital. The author's personal experience comprises eleven typical cases of classical causalgia in some 400 nerve injuries among the sailors and marines treated at the U. S. Naval Hospitals at Chelsea and St. Albans. The full-fledged condition is rarely seen in civilian practice, but an excellent account has been given by de Takáts.[43]

Many aspects of the causalgic syndrome suggest that it is a form of psychoneurosis, and this diagnosis has often and most unfairly been applied to these victims. The fact that the whole pseudoneurotic picture so often clears immediately following suitable intervention, when the sufferer has lost his dread of pain, no longer requires sedatives, and can resume a normal life, indicates that the personality disturbance is a result rather than the cause of an unendurable condition. In the past, when no successful treatment was known, causalgia was a frequent cause of drug addiction and led either to deterioration into hopeless invalidism or to self-destruction. Psychological studies made on service personnel after successful treatment in the present war (Mayfield and Devine,[33] Speigel and Milowsky,[40] de Takáts[43]) have not brought to light any predisposing psychogenic factors.

Phantom Limb. The awareness of a phantom limb is a common phenomenon after amputation. Fortunately, this sensation is not generally associated with pain, and it usually fades away with the use of an artificial arm or leg. Occasionally, however, it fails to disappear, or may return months or years afterwards in an intensely painful form. The cause of this return is usually additional trauma, which may be either organic or psychic. Recurrence of pain years afterwards (eighteen years in one of my cases) may be due to a fall with severe bruising of a leg stump and the resultant increase in scar tissue, or it may possibly be related to reduced circulation secondary to arteriosclerotic changes with advancing years. The etiological factors underlying the phantom phenomenon are still not definitely known. Unlike the causalgic states, the circulation and degree of sweating in the stump are rarely abnormal, and the phantom is not evoked by local stimulation or sudden psychic disturbances. Irritation within a neuroma of centrally conducting axones which supplied the missing part prior to its amputation was formerly believed to be the primary source of this peculiar sensation. A consideration of all the factors concerned, however, proves that this conclusion is not tenable. Evidence for this statement has been reviewed by K. E. Livingston[27] who cites the following points: (1) End bulb neuromas do not develop quickly enough to account for the early phases of the phantom limb, which may be present immediately after amputation. (2) Stimulation of a stump neuroma never produces the phantom sensation, but rather the usual tingling over the autonomous area of the peripheral nerve. (3) The typical phantom never represents irritation in the distribution of any single peripheral nerve: viz., there is no such thing as an "ulnar" or "peroneal" phantom. (4) Re-amputation rarely alters the phantom pattern.

Another argument against the neuroma's being the focus of the phantom impulses, and one which Livingston fails to mention, is the fact that the uncomfortable position of the missing extremity so often duplicates the situation which existed prior to amputation.

All of these features point to the fact that the phantom sensation is integrated at higher levels in the central nervous system. At first this may be situated at the reflex spinal level, as suggested by W. K. Livingston.[28] The fact that phantom pain can at times be relieved by spinothalamic tractotomy proves that its origin,

in this stage at least, must be situated either within the territory of the peripheral or of the spinal sensory neurone. Its persistence after cordotomy, which is often the case, indicates that the phantom may become a projection of the sensory cortex.

At times the evolution of a painful phantom has all the appearance of being a purely psychic manifestation. This is illustrated by an unusual case report of Lt. Colonel Frank Mayfield.[32] The patient, a tank soldier who had had his arm blown off above the elbow, had a perfectly comfortable upper arm stump until he applied for return to active duty. When this request was refused, he wanted to strike out with his amputated arm and clench his missing fist. He then became aware for the first time of his phantom hand, which remained clenched and painful. Although several neuromas were resected from the amputation stump, the phantom sensation was not relieved. However, as soon as he accepted the fact that he could not return to duty and asked for retirement, with the understanding that he could go overseas as a Red Cross Field Director, his phantom pain faded away. Evidence that this type of pain is often a central projection from the post-central cortex has been summarized by Riddoch[38] who points out that "the prevailing posture of the phantom is that of the part at the time of amputation. It is as if the postural model had become frozen when normal stimulation ceased." One thing is certain: Once this pattern has become fixed after prolonged physical and emotional disturbance, no interruption of the pain tracts can abolish it. The situation is similar to the tinnitus complained of by patients with Ménière's disease. This is usually cured by early section of the auditory nerve, but when it has been present for a long time it may persist, even though the attacks of explosive dizziness are successfully relieved.* Riddoch has given a most convincing argument for believing that the phantom sensation is a projection arising from the post-central sensory association areas in the cerebral cortex. According to him:

"Stimulation by the processes of healing of the proximal ends of the divided nerves evokes sensations which are projected and interpreted as if the limb were still present. As has been said, they are never quite normal. These paraesthesiae, through simultaneous excitation of the schema underlying tactile localization and shape, are projected and animate the surface or outline model of the absent part. Similarly, irritation of fibres concerned with postural sensibility gives rise to impulses which help to keep alive the postural model, so that the phantom is correctly placed and moves with the stump. These sensations, in the absence of pain, are, however, weak, so that, as a rule, only the peripheral segments, the hand or foot, which are most richly endowed with sensory end-organs and fibres, are represented in the phantom. Retention of the phantom is in part due to the abnormal qualities of the tactile and other sensations, in spite of their relative weakness and the antagonistic evidence from visual and other senses. During the stabilizing process of healing of the divided nerves, sensory impulses diminish, and sensations become correspondingly fainter, with the dual result that the phantom is increasingly less obvious in outline and projection of it is defective. In consequence, it gradually approaches the stump, into which it finally disappears and fades away. A new shape of the body is now accepted. In other words, there is no longer a conflict in evidence from the patient's senses. If, however, the phantom is painful, which is usually the result of grossly abnormal conditions in the stump, the phantom may persist indefinitely and retain its original position. Further, the hand and fingers are not only much more obtrusive and clearly defined, but more of the amputated part is represented by it. Voluntary movement is restricted or impossible because of aggravation of pain."

*I am indebted to Brigadier D. Denny-Brown, RAMC, for this interesting analogy.

If this concept is correct, the development of a central projection would be expected to take time to become established in the sensory cortex, a point which has been mentioned by Riddoch and recently emphasized by Air Commodore C. P. Symonds.[42]

A final point which requires consideration is the relationship between these three well known varieties of pain following injuries of peripheral nerves. Some writers believe that pain from a neuroma, causalgia, and the phantom limb phenomenon are merely different clinical manifestations of the same underlying disorder. Mayfield and Devine[33] believe that this similarity is remote and that causalgia is a clinical entity. Evidence now at hand also makes it possible to segregate the locally irritable end bulb neuroma and the phantom limb as separate and distinct entities. While resection of neuromas, when they are constantly subjected to muscle traction, lack of soft tissue protection, and pressure from a prosthesis, will usually eliminate local tenderness provided their reformation can be prevented, their removal in no way affects the pain of causalgia or a phantom limb. These last conditions are dissimilar, at least in the way they respond to emotional stimuli and react to the abolition of the peripheral hypothalamic discharge following sympathectomy. The response of causalgia is nearly always favorable, while a painful phantom cannot often be influenced by this procedure. Lt. Colonel Woodhall[54] has been fortunate enough to observe the response in two patients who suffered from both conditions simultaneously. After preganglionic sympathetic denervation of the upper extremity, the burning hyperpathia which had been so distressing after any exposure to cold or emotional stimuli disappeared, but the disagreeable cramp-like positions of the phantom hand remained.

While this discussion has been concerned with only three separate and distinct types of pain secondary to nerve injury, this does not imply that other varieties do not exist. Indeed many atypical varieties are seen. Sudeck's atrophy, painful osteoporosis, and the "minor causalgia" described by Homans[23] fall into this group, but only certain cases of the latter have followed direct injuries to the nerves. In these the pain has been less intense and less widespread than in the major causalgic syndrome, but many have responded equally well to chemical blocking and sympathectomy. Other less common conditions are seen so seldom and have so few points in common that it is impossible to give any general description of their symptomatology and treatment. Every neurosurgeon, however, is acquainted with old amputees who have crises of spasmodic severe pain in their stumps or other unusual manifestations which do not fall into any of the categories described above. Similar problems are occasionally encountered following severe fractures of the pelvis and hip. These are most difficult and yet stimulating cases to treat, as each constitutes a new and individual problem.

TREATMENT

Despite our lack of a fundamental understanding of post-amputation neuralgia, causalgia, and the painful phantom disturbances, several facts stand out clearly and require emphasis. Pain, considered by Hilton[22] and by Mackenzie[30] as a protective mechanism, may become a destructive force, dangerous to the victim's morale. As pointed out above, when pain of this type is allowed to become chronic, the cerebral cortex may become involved in its projection, so that no peripheral operation can relieve it; in addition, the patient usually develops an addiction to morphine and his personality deteriorates. Even in the less severe cases, painful hyperesthesia prevents active and passive movement of associated joint and soft tissue injuries, and thereby leads to contractures, osteoporosis, and a great variety of trophic disturbances. Watchful waiting, in the hope that the pain will disappear spontaneously, is therefore not advisable for

more than a very limited period. For these reasons we are forced to formulate a program to be undertaken when all conservative orthopedic, physiotherapeutic and neuropsychiatric measures have been tried and have failed.

Before recourse to surgery, it is always essential to bear in mind that any ill advised operation is likely to make the patient worse. The following pitiful case illustrates many of the difficulties in the treatment of post-traumatic pain. A French soldier of World War I received a penetrating wound of the hand, which led to chronic suppuration, fibrosis and pain. In the following ten years he had undergone a long series of operations including amputation above the wrist, resection of painful neuromas and subsequently progressive amputations up the arm which ended with a painful shoulder stump and an intensely disagreeable phantom of the original wounded hand. Periarterial sympathectomy of the subclavian artery and section of the posterior roots of the brachial plexus failed to put an end to his suffering, which was finally terminated in 1927 through suicide by hanging. At that time little was known about what to do and, equally important, what not to do about a case of this sort. We are learning slowly, and many points are illustrated by this tragic story. In the first place, it is vitally important not to undertake any ineffective procedures. Colonel F. M. McKeever[31] has observed that the pain in an amputation stump is usually increased by any operative procedure such as simple revision of flaps in which the nerve stumps are not even exposed. Progress has been made since World War I through the realization that certain procedures are useless and should no longer be considered. These include:

1. *Repeated Resections of Neuromas.*

2. *Neurectomies or Interruption of Nerve Trunks at Higher Levels.* Livingston[28] has recorded a resection of the brachial plexus in a painful upper arm stump without benefit, and the writer has had a similar experience; numerous other case reports since the time of Mitchell, Morehouse and Keen[35] are on record which attest its futility. Another variation of this procedure is the transection of a painful nerve trunk with immediate suture to prevent neuroma formation. Leriche[25] described its use but without striking results.

3. *Reamputation for the Relief of Pain.* Reamputation, as emphasized by Leriche[25] and Riddoch,[38] must never be considered, as the pain nearly always recurs in the new stump and usually is made a great deal worse. There is only one exception to this rule: When the stump is badly constructed and a liability on mechanical grounds, a reconstruction may be in order. Such a revision must be done at an early date, however, if it is to have any chance of relieving pain.

4. *Periarterial Sympathectomy.* Successful results in minor forms of causalgia and amputation stump pain after this operation have been recorded by Leriche[25] and Homans.[23] Leriche,[25] however, states that it should not be considered when the neuralgia is severe. Yet this unphysiological procedure is constantly mentioned in treatises on pain after nerve injury, such as Groff and Houtz's[17] recent book, but without the statistical backing of successful case reports. It is the author's personal feeling that the operation is non-specific and that its effects are due to the transitory rise in peripheral circulation (or reduction of vasomotor tone) that accompanies the increased elimination of heat following any injury to the tissues. Similar effects can be produced more simply by procaine block of the vasoconstrictor nerves or by fever therapy. In this connection, it is of interest to record the observation made by Mayfield and Devine[33] at the Percy Jones General Hospital that soldiers with malaria are often relieved of pain from nerve injuries during bouts of fever.

5. *Intrathecal Injection of Alcohol.* This procedure, proposed by Dogliotti,[9] has been advocated for the relief of painful amputation stumps in the lower extremity. On the Neurosurgical Service at the Massa-

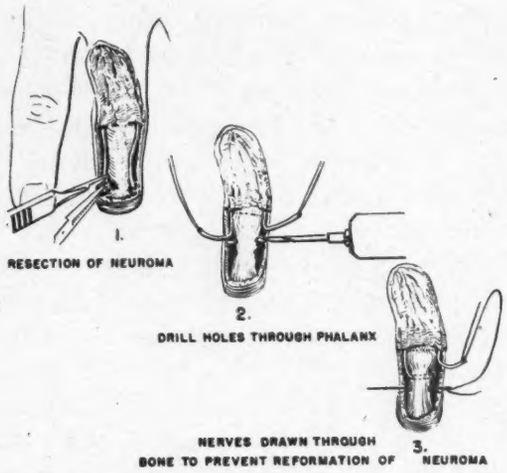

FIG. 2. Prevention of neuroma formation by drawing cut end of nerve through drill hole in neighboring bone, as suggested by Boldrey.[4] (Reproduced from article by White[50] with the kind permission of the U. S. Naval Medical Bulletin.)

chusetts General Hospital it has been successful only once out of seven trials. Furthermore, it carries a greater risk of paralyzing the bladder than section of the spinothalamic tract. For any patient who has chronic pain and is even a fair surgical risk, it is preferable to cut the pain tracts in the spinal cord.

6. *Posterior Rhizotomy.* Extensive sectioning of the posterior roots of the brachial plexus is a dangerous and mutilating procedure. The widespread and complete loss of sensation which follows is both annoying and incapacitating to the patient, if he has a useful stump. For this reason, and even more because the anesthetic stump usually continues to be painful, this procedure should never be undertaken. One of our patients with a painful amputation stump at the shoulder continued to suffer after division of all the posterior spinal roots from the third cervical down through the third thoracic. Riddoch[38] also emphasizes the futility of posterior rhizotomy in these cases, and states that he has seen the pain continue after the anterior as well as the posterior roots of the brachial plexus had been cut.

With the realization that the procedures mentioned above are ineffective and often dangerous, what is left for the surgeon to do when he is confronted with these serious problems? There are two simple operations that are often helpful and involve little chance of making matters worse:

1. *Single Resection of a Painful Neuroma.* A single resection of a sensitive neuroma is distinctly worth trying, particularly if the hyperesthesia is localized and can be relieved by local infiltration of procaine. (Table 1.) Formerly these neuromas reformed and pain recurred within a few weeks (Leriche,[25] Bailey and Moersch[1]). Injection of the fresh nerve stump with alcohol does little to delay the reappearance of the neuroma, but injection of 20 per cent formalin or a 1 per cent aqueous solution of gentian violet is more effective (Guttmann and Medawar[20]). This has proven fairly effective in five service patients, although follow-up observations do not extend beyond a few months. (Table 1.) Boldrey's[4] suggestion of drawing the nerve end through a drill hole in a neighboring bone (Fig. 2) is proving an effective method of preventing the reformation of a neuroma. At the U. S. Naval Hospitals in Chelsea and St. Albans, we have treated intercostal and digital nerves in this fashion in five patients with satisfactory relief of the local symptoms in four (Table 1.) Another technic, which was developed by Colonel R. G. Spurling and has continued to give satisfactory results in the hands of Lt. Colonel Barnes Woodhall at the Walter Reed General Hospital and of Captain White and Lt. Commander Hamlin at the U. S. Naval Hospital in Chelsea, is to cover the end of a nerve from which a neuroma has been removed with a snugly fitting cap of thin sheet tantalum. A description of this method has also recently been given by Coburn.[8] The procedure is illustrated in Figures 3A and B. This gave fairly satisfactory relief of the local symptoms in Case 5, but only temporary benefit in Case 7. Both Woodhall and White have had occasion subsequently to remove a few of these metallic caps, and have been impressed by the absence of neuroma formation. More recently Edds[12] has sug-

TABLE I

RELIEF OF LOCAL HYPERESTHESIA BY EXCISION OF NEUROMA MODIFIED BY PROCEDURES TO PREVENT REFORMATION

Case	Condition	Surgical Procedure	Result
1. Henry T. Pvt. USMC	Intercostal nerve caught in scar following gunshot wound. Neuralgic pain.	1) Diagnostic procaine intercostal block.	Temporary relief.
		2) Intercostal nerve severed on entering scar and drawn through drill hole in rib.	Nearly complete freedom from former pain at 1 mo.
2. Henry J. CM 3/c USN	Traumatic amputation of distal phalanges 4th and 5th fingers. Local tenderness and deep ascending neuralgia.	1) Plastic revision of poorly constructed 5th finger stump, excision of neuromata, and drawing of digital nerves through drill hole in middle phalanx.	Relief of local hyperesthesia only, but persistent ascending neuralgia and continued hyperesthesia in stump of 4th finger.
		2) See Table II.	
3. John G. S 3/c USN	Traumatic amputation 2nd and 3rd fingers. Exquisite pain in stumps and deep aching through hand and forearm. Cold, cyanotic, sweaty hand.	1) Digital nerves of 3rd finger freed from terminal neuromata and drawn through drill holes in proximal phalanx.	Relief of local hyperesthesia of middle finger, but no effect on deep ascending pain, index finger still hypersensitive at 2 mos.
		2) See Table II.	
4. Roy B. S 1/c USN	Severe scarring of sides of index finger by crushing accident. Local hyperesthesia of both sides of finger.	1) Paravertebral sympathetic ganglion block.	No effect on pain.
		2) Amputation of finger tip. Lateral digital nerve drawn through drill hole in proximal phalanx.	Loss of hyperesthesia over lateral side of finger at 7½ mos., with persistence of pain on medial side.
5. Philip C. Sgt. USMC	Traumatic amputation of tip of 5th finger, with repeated amputations to metacarpal level for local tenderness of stump and deep aching pain.	1) Resection of neuroma from medial digital nerve, and enclosure of stump in tantalum cap.	Relief of hyperesthesia only, with no effect on underlying neuralgia at 4 mos.
		2) and 3) See Table II.	
6. Cleveland J. SC 2/c USN	Traumatic amputation tip of middle finger with severe hyperesthesia.	1) Resection of neuromata and burial of digital nerve ends in drill hole through bone of 2nd phalanx.	Little improvement.
		2) Revision and shortening of painful stump. Digital nerves injected with 20% formalin.	A month later patient stated that all severe pain had gone. Slight tenderness persisted.
7. Francis O'C. V.A.P.	Traumatic amputation below knee with excruciating tenderness over end of peroneal nerve. Also, occasional shooting pain into missing lower leg.	Excision of neuromata of superficial and deep branches of common peroneal nerve. Two ends of nerve covered with tantalum cap (Fig. 3b).	Relief of local tenderness lasted 3 mos., then patient noted partial recurrence with superimposed diffuse neuralgia of stump.
8. Ingrid K. Y 2/c	Neuroma of thenar branch of superficial radial nerve following removal of ganglion.	Neuroma excised and end of nerve injected with formalin.	Returned to duty. At 3 mos. had mild discomfort on cold days.
9. Otis W. MM 3/c USN	Traumatic amputation through 2nd and 3rd metacarpal heads with local pain and hyperesthesia in scar.	Resection of 3 large neuromata and injection of nerve ends with 20% formalin.	Pain free at 2 mos.
10. Earl F. S 1/c USN	Traumatic amputation of ring finger through proximal phalanx. This stump so tender patient was unable to grip anything in the hand.	Excision of digital neuromata and injection of nerve ends with 20% formalin.	Pain free at 2 mos. and able to use hand freely.
11. Theodore Y. Sgt. USMC	Painful neuroma in cicatrix over radial side of ring finger.	Excision of neuroma of digital nerve and injection with 20% formalin.	Pain free at 1 mo.

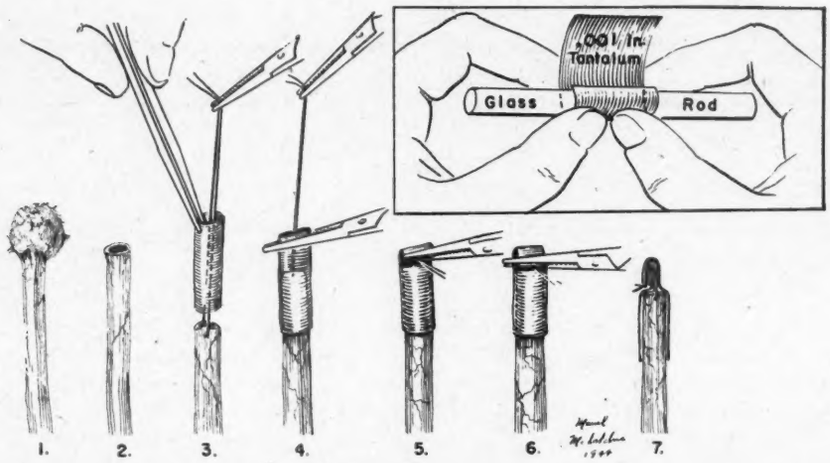

FIG. 3. Application of tantalum cap to stump of nerve for prevention of neuroma formation. A, (1) and (2), resection of painful end-bulb neuroma; (3), the amputated end of the nerve is transfixed by a fine silk stitch and covered by a sleeve of tantalum; (4), the open end of the sleeve is crushed in a hemostat; (5) and (6), the flattened end is turned back on itself and crushed again, thereby fixing it firmly to the end of the nerve. (Reproduced from article by White and Hamlin[52] with the kind permission of the J. of Neurosurgery.) B, *x*-ray showing cap of .001 inch tantalum placed over ends of superficial and deep peroneal nerves (Case 7).

gested painting the nerve end with 10 per cent solution of methyl methacrylate in acetone. In animal experiments it was found that the acetone causes complete chemical fixation of the nerve end, which is also imprisoned in an impervious plastic cap. Neuroma formation was never observed and the nerves tapered gradually to their blind ends. Theoretically, this method of encasing the end of the nerve in a non-irritant Lucite cap should be a simple and most practical solution of the neuroma problem, but we have been unable to obtain any human statistical results to date.

The methods reported above are all simple and theoretically sound procedures. They deserve careful clinical trial, but nevertheless it must be borne clearly in mind that the period of follow-up is still too short to permit any accurate assessment of their value.

2. *Sympathectomy.* In patients with vasomotor and emotional disturbances, which are so commonly found in these painful states, much can be done by the elimination of the regional sympathetic outflow to the painful extremity. This can be accomplished either by repeated chemical blocking with procaine or by sympathectomy. The technic of these procedures has been described by White and Smithwick[11] and by White[11] in Bancroft and Pilcher's "Surgical Treatment of the Nervous System." The relief of pain, as stated above, is not brought about by any interruption of afferent impulses, as these do not run in the peripheral sympathetic system, but by correction of abnormal circulation and interruption of sympathetic influences on the irritated sensory nerve fibers. Evidence for this is that these patients are more comfortable when protected from psychic stimulation (Doupe et al.[11]) and during the reduction of sympathetic vasoconstriction which occurs in warm weather, in sleep, or when circulation is improved after artificial fever induced in a hypertherm, by injection of foreign protein, or by a malarial chill (Mayfield and Devine[33]). By far the most practical test is the paravertebral infiltration of procaine around the upper thoracic or lumbar sympathetic ganglia. Many favorable results have been reported by Leriche,[25] White and Smithwick,[53] Homans,[23] de Takáts and Miller,[44] Livingston,[28] and by Doupe and his collaborators.[11] Sometimes long-lasting relief has followed a single or several repeated injections.

When pain is relieved during the period of sympathetic block, but reappears as the drug is absorbed, there is a very good chance that surgical interruption of the regional sympathetic ganglia will bring about lasting relief. In cases of burning pain and hyperesthesia, this is almost a certainty. Experience with nineteen such cases is summarized in Tables II and III. This method is most effective when the pain results from a nerve lesion in the lower arm or leg with associated vasospasm, and particularly when the pain is increased by emotional stimuli. The improvement in Case 14, in which pain developed in a mid-thigh stump with arteriosclerotic changes thirty years after amputation, was a distinct surprise, as there were no associated vasomotor or psychic correlations. Here the immediate result was excellent, but after eight months was no longer satisfactory, due presumably to some further reduction in the circulation of the scar. In Case 5, a Marine sergeant with a painful fifth finger stump of ten years' duration, sympathectomy has failed to relieve deep aching pain in the hand completely, but the patient is nevertheless distinctly grateful for the partial relief and the greatly improved circulation in his hand. In all eleven of the patients with typical Weir Mitchell causalgia, sympathectomy has been a striking success. (Table III.) In these cases, local neurolysis and freeing of the nerve from a surrounding cicatrix or resection of a lateral neuroma are seldom successful (Mayfield and Devine,[33] Speigel and Milowsky[40]). Neurolysis or suture of the injured nerve to relieve pain is justifiable only when there is definite paralysis and when the causalgia is so mild that the surgeon can afford to wait for a period of months while the irritated nerve fibers regenerate. If the pain is really severe, it is far better judgment to perform the sympathectomy first (provided there has been a promising response to paravertebral procaine block) and to postpone any necessary local repair of the nerve trunk until afterwards. Patient 22 in Table III serves to illustrate this point. Here a bullet had passed close to the median nerve, which was bound down by a band of scar tissue to the deep head of pronator radii teres. (Fig. 1B.) Freeing the nerve and transplanting it into a bed of healthy muscle had no effect on the burning pain in the hand, but this was later relieved by sympathectomy.

Preganglionic denervation of the upper extremity and resection of the second and third lumbar sympathetic ganglia are both

TABLE II

RELIEF OF LOCAL PAIN AFTER AMPUTATION BY INTERRUPTION OF SYMPATHETIC FIBERS

Case	Condition	Surgical Procedures	Relief
2. Henry J. CM 3/c USN	Traumatic amputation of distal phalanges of 4th and 5th fingers. Very cold, cyanotic, sweaty hands.	1) See Table 1.	
		2) Paravertebral procaine block T1-T2.	Temporary relief.
		3) Upper thoracic preganglionic sympathectomy.	Warm hand and arm free of former deep pain at discharge (3 weeks).
3. John G. S 3/c USN	Traumatic amputation 2nd and 3rd fingers. Local hyperesthesia in 3rd finger had been relieved by excision of neuroma, but without effect on neuralgia of hand and forearm.	1) See Table 1.	
		2) Paravertebral procaine block T1-T2.	Temporary relief.
		3) Upper thoracic preganglionic sympathectomy.	Complete relief of ascending neuralgic pain. Patient still complained of hypersensitive index finger, but was able to return to limited duty.
5. Philip C. Sgt. USMC	Traumatic amputation tip of 5th finger with repeated amputations to metacarpal level for local hyperesthesia and deep ache in hand and arm. Cold, cyanotic hands.	1) See Table 1.	
		2) Procaine block of upper thoracic ganglia.	Relief for 2 hours.
		3) Upper thoracic preganglionic sympathectomy.	Nearly complete relief of deep aching pain in hand and arm at 3 months.
12. Roger P.*	Crush of index finger and amputation associated with cold, clammy hand; pain in hand radiating up inner arm to pectoral region.	1) Reamputation of finger.	None.
		2) Paravertebral procaine block T1-T2.	Relief for 2 hours.
		3) Cervicothoracic ganglionectomy.	Slight recurrence of pain 1 yr. after operation, on partial recovery of vasoconstriction and sweating.
13. Roland L.*	Traumatic amputation of index finger associated with cold, sweaty hand.	1) Reamputation of finger.	None.
		2) Paravertebral procaine block T1-T2.	Transitory relief.
		3) Cervicothoracic ganglionectomy.	Permanent relief.
14. James B.*	Burning pain developing in stump 30 years after thigh amputation; pain present for 3½ years.	1) Section spinothalamic tract with sensory level at T12.	Relief for 4½ mos. with recurrence following transurethral prostatectomy.
		2) Paravertebral lumber procaine block.	Relief for 2 days.
		3) Paravertebral lumber procaine block.	Relief for 4 weeks.
		4) Paravertebral lumber procaine block.	Relief at discharge.
		5) Lumbar sympathectomy L1-L3.	Relief for 7 months, then partial recurrence.
15. Henry C. S 2/c USN	Traumatic amputation of 3rd toe, with severe pain in stump and bottom of foot. Aggravated by cold, not by psychic stimuli.	1) Paravertebral procaine block.	Temporary relief.
		2) Lumbar sympathectomy L2-L3.	Complete relief at 2 mos.
16. James L. AB R.N.	Traumatic metatarsal amputation with painful vasospasm. Deep ache in end of foot, which became much worse in cold weather and ascended to knee.	1) Paravertebral procaine block.	Temporary relief.
		2) Lumbar sympathectomy L2-L3.	Excellent result.

* Civilian cases, treated at Massachusetts General Hospital, Boston.

TABLE III

RELIEF OF CAUSALGIA BY PREGANGLIONIC SYMPATHECTOMY

Case	Wound	Paralysis	Distribution of Pain	Time of Onset after Wounding	Hyperpathia	Trophic Changes	Temperature of Extremity	Sweating	Relation to:		Operations in Addition to Sympathectomy	Result of Sympathectomy
									Cold	Emotion		
17. Chas. R. Pfc. USMC	Small shell fragments L. upper arm.	Median nerve (partial)	Entire hand.	Few hours.	+++	+++	Cool.	+++	+++	+++	None.	Complete relief, now plays strenuous games.
18. Fred. S. Pvt. USMC	Shell fragments upper arm and forearm.	Median nerve (partial), ulnar nerve (complete).	Entire hand.	5 hours.	+++	++	Cool.	+++	+++	+++	Subsequent median neurolysis and ulnar nerve suture.	All hyperesthesia cleared. Slight residual ache in finger tips.
19. John H. Maj. USMC	Upper humerus fractured by shell fragment. Aneurysm.	Median nerve (complete), ulnar nerve (partial).	Entire hand.	Immediate.	++	+	Cold.	++	++	+++	Aneurysmorrhaphy. Median nerve will require suture later.	Complete relief.
20. Norman C. Pfc. USMC	Machine gun bullet passed between two upper forearm bones.	Median nerve (partial).	Entire hand.	Few hours.	++	+++	Cool.	++	++	0	Previous neurolysis & partial suture of median nerve with partial relief.	Complete relief.
21. Chas. M. Pfc. USMC	Rifle bullet through upper arm. Artery severed.	Median & ulnar nerves (complete).	Entire hand.	2 weeks after operation for aneurysm.	++	+	Cold.	++	++	++	None.	Complete relief.
22. Nathan V. Pvt. USMC	Rifle bullet through upper forearm, fractured ulna.	Median nerve (partial).	Median distribution.	.....	++	+++ (median area).	Cold.	++	+	++	Neurolysis median nerve without relief. (Fig. 1.)	Complete relief.
23. Robt. B. Cpl. USMC	Bullet wound brachial plexus, fractured clavicle, severed artery.	Median and ulnar nerves (partial), medial antebrachial cutaneous nerve (complete).	Entire hand.	1 week.	+++	++	Cool.	0	++	+++	None.	Hyperpathia of hand gone, but at times slight residual pain elbow and wrist.
24. Alfred D. Pfc. USMC	Mortar wound median side of arm, axilla to mid forearm.	Median nerve (partial).	Median area of hand.	Day after wound.	+++	+	Cool.	+	++	++	None.	Complete relief.
25. Howard W. Pfc. USMC	Bullet wound below elbow.	Median nerve (partial).	Median area of hand.	Immediate.	++	+	Cold.	+++	++	++	Previous median neurolysis, without improvement.	Complete relief.
26. Harold O. Pfc. USMC	Shell fragment wound of internal condyle of elbow.	Ulnar nerve (partial).	Ulnar area of hand.	.....	++	+	Cold.	+++	++	++	None.	Complete relief.
27. Wm. M. Cpl. USMC	Phosphorus grenade fragments in lower leg.	Common peroneal (partial), sural nerve (complete).	Entire foot and toes.	Immediate.	+++	++	Cold.	++	++	++	None.	Nearly complete relief.

safe and non-mutilating procedures. They therefore deserve serious consideration and early testing by procaine block when incapacitating pain persists in a peripheral nerve wound or amputation stump, especially when this is accompanied by abnormal vasomotor, sudomotor or psychic manifestations. When pain disappears for the duration of the chemical sympathectomy, the patient with stump neuralgia should be told frankly that, while complete relief cannot be guaranteed, there is distinctly better than an even chance for a satisfactory outcome, and a certainty that the abnormal peripheral circulation and sweating will be rectified. In the case of the worst causalgias, the outlook is even more promising. The results in the eleven cases summarized in Table III are almost completely satisfactory, and a similar outcome has been recorded in twenty-nine other cases reported by Doupe and his co-workers,[11] Mayfield and Devine,[33] and by Speigel and Milowsky.[40]

Examination of Table I shows that the local tenderness over a neuroma can often be relieved by removing it, provided regrowth of axones into the scar can be prevented. On the other hand, widespread, deep, aching pain or hyperesthesia are not influenced by this procedure, but often respond well to sympathectomy. (Table II.)

How often the painful phantom phenomenon can be relieved by sympathectomy is still uncertain. De Takáts[43] has recommended its trial and Livingston[28] has reported some favorable results, but in the author's limited experience this procedure has not proven successful. Woodhall[54] has reported a most instructive case in which a young Army lieutenant suffered simultaneously from burning causalgic pain in his lower amputation stump and from a disagreeable phantom of the missing hand contracted in the position in which he last saw it prior to its amputation. A month after an upper thoracic preganglionic sympathectomy the patient stated that he was relieved of his causalgic pain but that the phantom of his hand still persisted.

When these relatively simple and innocuous operations cannot be used the surgical attack must be shifted to the central nervous system. Before recourse to more radical intervention on the spinal cord or brain can be considered, all aspects of the problem should be reviewed with a competent neuropsychiatrist. Lidz and Payne[26] have cited the case of a young soldier who shot off the middle finger of his right hand while cleaning his rifle. Typical severe causalgia developed seven weeks later when he heard that his unit believed that the wound was self-inflicted to avoid service at the front. The pain persisted until the situation was explained to him and he was given encouragement under the influence of sodium pentothal. When he decided to prove himself in combat and regain the respect of his friends, the entire condition cleared up.* Successful results of this sort are, unfortunately, extremely rare.

The available surgical procedures on the spinal cord and brain are mutilating operations. They may involve serious complications and, if they fail, will add another psychic trauma with further reduction of the patient's morale. Recourse to such radical surgery can, therefore, be undertaken only in desperate cases in which pain is so severe that the patient threatens to become an addict to morphine, a psychopathic problem or a suicide.

3. *Section of Spinothalamic Tract.* Interrupting the anterolateral spinal (spinothalamic) tract by which painful impulses reach the brain is in general far more effective than cutting the posterior roots over which they enter the spinal cord. From personal experience to date, there is good reason to believe that pain and tenderness which are located within the stump itself can usually be relieved by

* It would be of great theoretical interest to know whether this dramatic result was brought about by lessening the tonic sympathetic impulses to the extremities which are so greatly increased at times of emotional disturbance. Cobb[7] has recorded instances of the development of Raynaud's phenomenon during periods of intense psychic strain, so this possibility would fit in well with Doupe's[11] theory of production of causalgic pain.

TABLE IV

RELIEF OF LOCAL PAIN AFTER AMPUTATION BY SECTION OF SPINOTHALAMIC TRACT*

Case	Condition	Level of Analgesia	Relief
14. James B.	See Table II.	12th thoracic segment.	Relief for 4½ months, with recurrence following transurethral prostatectomy. This patient's problem complicated by a senile psychosis. (See Table II.)
28. William D.	Gritti-Stokes amputation for thromboangiitis obliterans, then complained of deep aching pain in stump, 3½ years' duration.	9th thoracic segment.	To death, 3½ years later; this patient subsequently developed pain in stump of other leg after a second Gritti-Stokes amputation, and painful gangrene of fingers; died after cervical cordotomy on opposite side.
29. Nellie T.	Burning pain in stump since thigh amputation for osteomyelitis 8 years before; at other hospitals had had unsuccessful sciatic neurectomy, multiple excisions of neuromas and intrathecal alcohol injection; latter caused bladder disturbances for 1 year.	8th thoracic segment.	Complete relief at 3 mos.
30. Emma H.	Mid-thigh amputation following septic abortion; local pain in stump of 2 years' duration; previous intrathecal alcohol injections had paralyzed bladder without mitigating the pain.	10th thoracic segment.	Complete relief for over 7 years, but has complained of radicular pain at level of laminectomy. This has disappeared in last 4 years.
31. Ralph T.	Traumatic thigh amputation above knee in World War I; for past 7 years crises of bursting pain in stump of great intensity, especially at night. Pt. had well-formed, non-tender stump, and walked freely with artificial leg. Temporary relief following spinal anesthesia to T6.	9th thoracic segment.	Complete relief to date, 2½ months.
32. Daniel M.	Traumatic low thigh amputation 3 years previously. Tenderness and burning pain in stump, driving pt. to drink, unable to use artificial leg. Previous excision of sciatic neuroma with recurrence and local tenderness. Temporary relief following full spinal anesthesia.	9th thoracic segment.	Complete relief at 6 weeks. Pt. walked out of hospital on his artificial leg.
33. John D.	Low thigh amputation 14 years previously for malignant tumor of tibia, followed in last 4 years by deep aching, burning pain. Pt. becoming an alcoholic on this account. No local areas of tenderness.	11th thoracic segment.	Complete relief at 3 weeks.

* All of these were civilian patients, operated upon at Massachusetts General Hospital, Boston, by Drs. W. J. Mixter, J. S. Hodgson, and J. C. White.

cordotomy. Seven cases are summarized in Table IV, six of which obtained satisfactory relief. The situation in the other, Case 14, was complicated by his senile psychosis and mental attitude toward his complaint.

In the case of severe phantom manifestations the decision as to whether relief can be obtained by spinothalamic tractotomy becomes most difficult. In the extensive experience of Bailey and Moersch[1] at the Mayo Clinic, this operation has failed consistently. Riddoch,[38] however, is not so pessimistic and has stated that "when pain in the phantom is successfully abolished by lateral chordotomy or early removal of abnormalities in the stump, the phantom may behave as if it had been painless from the first." These points are

TABLE V

RELIEF OF PHANTOM LIMB PAIN AFTER AMPUTATION BY SECTION OF SPINOTHALAMIC TRACT*

Case	Condition	Level	Relief
34. Charles W.	Pain in phantom foot for 18 years following thigh amputation; 2 previous unsuccessful resections of neuromas.	Not recorded.	At 2¼ years patient remains comfortable, although at times there is slight throbbing sensation in phantom little toe; spasmodic jumping of stump has ceased.
35. Arthur N.	Crushing pain in phantom ankle following hip disarticulation for sarcoma 2 months previously.	7th thoracic segment.	In good condition and free from pain at 27 months, but has had awareness of phantom with some sense of stiffness in foot and big toe.
36. Homer A.	Pinching, burning pain in phantom foot 7 months after hip disarticulation.	9th thoracic segment.	Complete loss of phantom sensations at 8 months; still complains of spasmodic jerking of stump with sense of muscle cramp and of mild radiculitis at level of laminectomy incision.

* All of these were civilian patients, operated upon at Massachusetts General Hospital, Boston.

borne out by Case 33 below. Nevertheless, Riddoch agrees that no relief can be expected when the pain has been stamped indelibly on the cerebral cortex. This means that a cordotomy performed without too long delay, and particularly before the patient becomes addicted to morphine, stands the best chance of success. Although it has not yet been proved. I believe that spinal anesthesia should offer the best chance of weeding out the patient with pain of central origin following an injury to the lower extremity.* In cases of arm pain, procaine block of the brachial plexus can accomplish the same purpose, and it has been demonstrated that it does not relieve pain which originates in the cerebral cortex (Michelsen[34]).

On the Neurosurgical Service at the Massachusetts General Hospital we have cut the spinothalamic tract in three patients complaining of painful leg phantoms. (Table v.) It will be seen that the severe crushing or pinching pains in the phantom foot have been relieved in each instance. In the first patient (Case 34), whose phantom sensations had been present for eighteen years, it is remarkable that relief from pain should have been so complete. He writes: "No sensation to speak of in the missing leg, but some throbbing at times in the little toe and ankle bone. No movement of the foot or toes. The operation has also eliminated the spasmodic jumping of the stump to almost 100 per cent." The second patient (Case 35) has had a sense of stiffness in his phantom ankle and big toe but no pain. The third (Case 36) states that he has lost all sense of his phantom, but that when the muscles of his stump contract he is still aware of the cramp-like sensations. This is not a sufficiently large series from which to draw definite conclusions, but it does prove that cordotomy can help in certain cases. So far there have been no published successful reports of cordotomy performed for phantom pain in the upper extremity, although the operation has been attempted three times by Grant[16] without success. For a high spinothalamic tractotomy the incision in the anterolateral column is made at the second or third cervical segments, but it is not easy to raise the level of analgesia to the uppermost outflow of the brachial plexus.

* A recent experience of Dr. W. J. Mixter's[36] at the Massachusetts General Hospital proves that this is not invariably true. The patient, who had local pain in his thigh amputation stump which radiated toward his missing knee, continued to experience his pain after an apparently complete spinal procaine block. Cordotomy, however, has resulted in complete relief over a period of nine months. Dr. Stanley Sarnoff is now making a careful study of the diagnostic value of spinal anesthesia in this field at the Massachusetts General Hospital, and his results will soon be reported.

It is more logical to cut the spinothalamic tract at the medullary level (Schwartz and O'Leary;[39] White[48]). In the case reported by White neuralgic pain, which involved both the upper thoracic and upper cervical roots, was successfully relieved, although at the expense of some residual ataxia. This complication occurred because in these earlier attempts the spinothalamic tract in the medulla was sectioned just below the level of outflow of the most caudal vagal rootlets, too close to the vestibular nuclei at the base of the restiform body. Sweet,[41] in four operations performed during the recent war for intractable pain entering the cord over cervical roots, has avoided this risk of injury to the inferior cerebellar peduncle by making the incision into the side of the medulla at a slightly lower level. He has obtained effective analgesia over the entire arm area in each case without any persistent complicating disturbance of postural control, and in two patients with an adequate period of postoperative observation the relief appears to be permanent. One of these patients had the phantom of a painful hand protruding from his shoulder amputation stump. Much further surgical experience is required to establish the chances of successful relief of phantom pain. At present cordotomy appears to give this in about half of the reported cases, but when its use is strictly limited to those subjects in whom the pain can be relieved by complete spinal anesthesia, the percentage of effective results should rise to a more satisfactory level.

In cases in which pain is definitely of central origin two methods have recently been proposed for its surgical elimination at the highest levels in the brain itself:

4. *Resection of Sensory Cortex.* In certain sufferers from major amputation stump neuralgia we shall be forced to decide whether, in the presence of phantom sensations with evidence of psychic projection of the painful manifestations, we are justified in taking Riddoch's[38] and Leriche's[25] still earlier suggestion and extirpating the postcentral convolution of the cerebral cortex. Riddoch believes that the phenomena of the phantom limb, such as the persistance in the phantom of pain and postural sensations which antedate the amputation, can be explained only on the basis of cortical representation. He has stated that "destruction of the cortical sensory receptive mechanism in the parietal lobe, which is concerned with the development of postural and surface models and with recognition of change, causes immediate abolition of the phantom limb." This theory is corroborated by the case reported by Head and Holmes[21] in which disappearance of a post-amputation phantom foot followed a lesion of the opposite parietal cortex. De Gutiérrez-Mahoney[18] has put this theory to the test and carried out resection of the postcentral sensory cortex in a patient with a very disagreeable phantom arm. After two years the result remains a striking success. He has since had another equally satisfactory result.[19] Carmody and Sweet[6] have just relieved the phantom finger sensation in a third patient after a forearm amputation, but the postoperative period of observation is still too short to be sure of their success. With lesions which involve the corticothalamic connections, as pointed out by Gerstmann[14] and Nielsen,[37] the patient may lose awareness that he possesses portions of the opposite side of his body. This is the antithesis of the phenomenon of the phantom limb and gives addition backing for the surgical ablation of the postcentral convolution of the cerebral cortex. Michelsen[34] has reported five instances which we have observed in the neurosurgical clinic of the Massachusetts General Hospital. In one of these patients a depressed parietal fracture, causing cortical irritation of the postcentral arm area, produced pain very similar to that experienced from a disagreeable phantom to radiate down the opposite arm. By infiltrating the brachial plexus it was possible to obtain a complete motor and sensory paralysis, yet the pain which seemed to originate in her arm remained unaltered.

It is obvious that this projected attack on the highest station for sensation in the cortex is too new to permit any definite conclusions to be drawn, but the theory can be tested by turning down a small parietal bone flap under local anesthesia, then identifying the motor and sensory areas by electrical stimulation and infiltrating the first postcentral convolution with procaine.

5. Release from States of Agitation and Introspection by Frontal Leucotomy. A final possible approach to the problem of the unbearable phantom is the elimination of the sufferer's introspection and self-centered concentration on his condition which is the natural outcome of long-standing intractable pain. Ordinary psychotherapeutic methods alone have not been effective, but on theoretical grounds bilateral frontal lobotomy might accomplish this result, as it has benefited so many of Freeman and Watts's patients suffering from agitated states.[13] A successful operation of this type has been performed by Lt. Colonel Van Wagenen.[46] This patient had had a series of forty-five operations for chronic osteomyelitis, ending up with an amputation of the leg through the pelvis. He continued to have intractable pain in his phantom limb and was a confirmed morphine addict. In the year that has elapsed since the lobotomy he has recovered from his drug addiction, is able to look after his house, and has only rare phantom sensations in his amputated leg, which are no longer a cause for serious concern.

Experience with these two operations is limited to three successful cases with adequate periods of postoperative observations. The first removes the sensory cells which may give rise to disagreeable phantom sensations, while the second does away with the subject's introspection and preoccupation with his complaints. In conclusion, it is well to restate that both must still be regarded as purely experimental procedures which will require extensive investigation before their therapeutic value can be estimated. At present neither of these operations is to be considered except under pressure of extreme suffering and in a patient who threatens, unless relieved, to deteriorate into hopeless invalidism. If successful, they will open up a new method of surgical intervention for heretofore hopeless situations, conditions which cause so much pain and incapacity that the patients either become neurotic invalids and drug addicts or suicides. Every war has produced a new crop, and it is to be hoped that we shall have learned how to relieve the majority of them as one of the few happy by-products of the recent conflict.

SUMMARY AND CONCLUSIONS

1. Pain following injuries to peripheral nerves has been a serious wartime problem. In neuromas with local tenderness and hyperesthesia it is often a cause of prolonged disability. In the severer grades of causalgia and phantom limb pain it may result in prolonged torture with ultimate addiction to narcotics, deterioration of personality or even suicide.

2. The unsatisfactory results of operations for pain complicating nerve injuries in the last war were valuable lessons in what the surgeon should avoid. In dealing with these unstable individuals any unsuccessful surgical intervention can only result in making matters worse. Procedures which are now generally known to be ineffective or even definitely harmful include repeated resection of neuromas, neurectomy or nerve injections at higher levels, posterior root section and re-amputation. While occasional successes have been reported after periarterial sympathectomy, this operation is not effective in the major neuralgias and its results can be duplicated in the less severe cases by paravertebral injection of procaine or by fever therapy.

3. The experience of this war has shown that causalgia and many forms of diffuse hyperesthesia can be treated effectively by sympathectomy. The local tenderness and

discomfort over a mechanically irritated neuroma can often be relieved by its resection, provided that effective measures are taken to prevent reformation. Other varieties of intense aching or lancinating pain centered in the lower extremity generally respond well to cordotomy. The unbearable discomfort of a phantom extremity can be removed by spinothalamic tractotomy, provided the operation is done before the psychic manifestations are permanently engraved on the cerebral cortex. Even under these circumstances there is promising evidence that the phantom sensation can be removed by resection of the sensory cortex, or the patient's concentration of his symptoms released by prefrontal leucotomy.

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In neurosurgery, as in other fields, the most important diagnostic factors are the careful history and physical examination. Valuable adjuncts, such as perimetry, audiometry, roentgenography, electroencephalography, and cerebrospinal-fluid studies, may be essential.

From "Surgical Treatment of the Nervous System" edited by Frederic W. Bancroft and Cobb Pilcher (J. B. Lippincott Company).

THE REPAIR OF PERIPHERAL NERVE LESIONS*

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"WHEN nervous tissue is cut, it does not repair itself neither does it reunite." This statement was made by Hippocrates and even though his concept of nervous tissue was not precise and he used the term to include tendons, ligamentous structures, and in fact all "white" tissue in the body, one may assume that at some time, he had the occasion to note the failure of an actual nerve to repair itself. We must realize then that the problem of nerve repair is as old as the art of medicine.

A topical survey of the literature on the subject will bring out the fact that the spotlight of attention is focused upon this problem during every war. Medical journals published during the last war were filled with articles dealing with the diagnosis and treatment of nerve injuries.

During that period, the technic of nerve suture was greatly improved and certain principles enunciated: (1) The recovery is better in early repair, however, the recovery in late repair may be good (Delageniere had one case twenty-eight months). (2) Tension at suture line is a serious impediment to recovery. (3) Orientation of stumps with regard to internal topography is essential. (4) The formation of scar tissue in and about suture line prevents recovery. (5) The suture material used must be innocuous. (6) A poor vascular bed for repaired nerve fosters the development of fibrous tissue. At the same time, laboratory experiments were carried out that gave hope in a more radical approach to the treatment of extensive nerve injuries. Huber,[1] Nageotte[2] and others were successful in using formalin fixed homologous nerve grafts in animals. Their technic was enthusiastically applied to human material, however, there has been no known instance of the successful grafting of a large nerve trunk.

It is interesting to note that following this period, a lessening of interest in the problem and a wave of pessimism and doubt developed which was in sharp contrast to the ambitious and hopeful attitude of the surgeons of the war period itself, and in spite of the enormous number of nerves operated upon during and following the last war, it is almost impossible today to get a clear picture of the results obtained. In nearly all the series reported, only a small percentage of the cases in which the patients were operated upon were carried to final evaluation. The value of such reports is further vitiated by the fact that the criteria for determining the degree of recovery was not standardized. The following representative reports show the disparity that existed in the records of that time.

One cannot believe that the type of material varied to any great extent or that there was so much difference in the skill of the various surgeons; the difference, therefore, lay either in the selection of the material or in the method of evaluating the results.

It was our problem at the beginning of this war not only to operate upon and repair nerves to the very best of our ability but to see to it that a study of our results would be of some value to others and that the evaluation of our results either good or bad would not be open to questioning. We were fortunate at the time the neurosurgical service was initiated at the Naval Hospital at St. Albans in 1943 in being able to make arrangements for all cases of peripheral nerve injury to be examined by skilled and impartial observers, who not only aided us in the study of the cases but

* From the Neurosurgical Service of the U. S. Naval Hospital, St. Albans, N.Y.

also served as judge and jury in passing upon the final results. We are deeply grateful to Dr. Joseph Moldaver and Dr. Ernest Hertz, of the staff of the New York Neurological Institute and Dr. I. M. Tarlov of the New York Medical College for their tireless cooperation in this work, and to the National Research Council for its support.

In brief, each case study consisted of the following: (1) A neuroclinical examination including sensory, motor and vasomotor evaluation, (2) electrodiagnostic tests with particular emphasis upon chronaxie,[10] (3) sweating and skin resistance tests, (4) microscopic studies giving information as to the condition of the proximal and distal stumps of the nerves repaired and (5) motion pictures were taken before operation and during recovery.

TABLES

(A) THE SURGEON GENERAL'S REPORT OF THE MEDICAL DEPARTMENT OF THE U.S. ARMY IN WORLD WAR I: END RESULTS OF 400 CASES OF NERVE SUTURE.

Nerve	Good	Mediocre	Negative
Brachial plexus	0	100	0
Radial	11	66	22
Median	12	56	32
Ulnar	5	72	22
Sciatic	1	60	38
Peroneal	0	50	50
Tibial	0	50	50

(B) RESULTS OF SUTURES ON PERIPHERAL NERVE INJURIES BY VARIOUS AUTHORS:

	Delageniere[3]	Jalcowitz[4]	Kennedy[5]	Stopford[6]	Platt[7]
Total cases	142	57	?	271	150
Successful or recovery	85.9%	0	73%	90%	79%
Partially successful	11.2%				
Extensive improvement		2			
Moderate improvement		19			
Failure (or no recovery)	2.8%	28	27%	10% 16*	21%

* No recovery recorded in six to thirteen months.

(C) RESULTS OF LOYAL DAVIS:(8)

Nerve	Good	Fair	No Results
Ulnar	8	11	1
Median	5	3	1
Radial	4	5	1
Combined median-ulnar	3	4	1
Brachial plexus	0	3	4

(D) RESULTS OF SECONDARY NERVE SUTURE AFTER FOERSTER:(9) (CENTRAL EUROPEAN)

Author	No. of Cases	Recovery Per Cent	Good Per Cent	Fair Per Cent	Failure Per Cent
Foerster	370	96.0	55.0	42.0	3.0
Stracker	147	75.0	13.0	62.0	25.0
Roper	84	22.7	6.0	16.7	77.3
Ranschburg	414	35.7			64.3
Stoffel	127	62.0	23.0	36.0	38.0
Spielmeyer	100	59.0	23.0	36.0	41.0
Borchardt	59	59.3			40.7
Perthes	74	66.0			34.0
Lehmann	69	39.1			60.9
Mauss and Kruger	42	43.0			57.0
Kunzel	44	67.7			32.3
Pelz	18	22.2			77.8
Moro	17	82.3			17.7
Hoffman	22	81.8			18.2
Herzog	16	12.5			87.5
Wexberg	57	54.5			45.6
Ranzi	31	48.4			51.6
Kakula	40	70.0			30.0
Rost	24	56.5			44.5
Cassirer	78	51.0			49.0
Steinthal	40	27.5			72.5
Total	1873	60.0			40.0

ULNAR NERVE LESION CHRONAXIE VALUES IN 1/1000 OF A SECOND*

	Preop.	Postop 2 Mo.	4 Mo.	8 Mo.	10 Mo.	12 Mo.
Abd. Min. Digits	20	16	12	7.2	1.2	1.2
1st Dorsal interos	18	18	12	6.8	5.6	3.2
2nd Dorsal interos	12	10	9.2	4.4	5.2	2.4
3rd Dorsal interos	13.2	14	9.2	5.6	6.8	2.0
4th Dorsal interos	13.2	14	9.6	4.8	3.2	2.8
Clinical Recovery Rating		0	0	M2	M3	M4
(Normal Chronaxie)	.16 to .30					

* Chronaxie studies of a single case illustrating anticipation of recovery before clinical signs, and continued drop in chronaxie indicating maturation of nerve fibers.

We have great confidence in chronaxie as an extremely valuable diagnostic aid; in our experience it has been more reliable than electromyography and more practical than strength duration curves and stimulus-tetanus ratios. In evaluating our results, we have used a 0 to 5 scale for both motor and sensory recovery. A slight modification of the Oxford scale was used for the motor evaluation as follows:

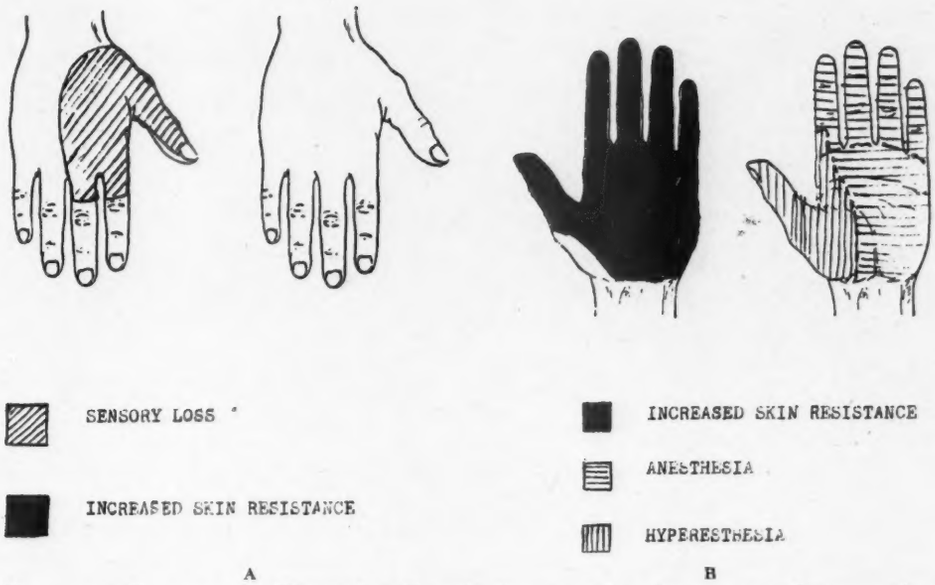

FIG. 1. A and B, two cases illustrating disparity between somatic sensory and autonomic distribution.

0. No contraction, high chronaxie values.
1. Flicker or trace of contraction or drop in chronaxie.
2. Active movement of some of affected muscles.
3. Active movement of majority of affected muscles.
4. Active movement against resistance, i.e., useful function.
5. Normal power and *all* muscles reinnervated by chronaxie test.

For sensory evaluation, we have followed our own scale:

1. Return of deep pressure sense, often with distributional confusion.
2. Touch and/or pain sense.
3. Distinction of sharp and dull.
4. Localization of touch.
5. Two-point sensibility and sterognosis.

(The presence of hyperasthesia or "distributional confusion" drops the rating by one.)

Our findings in the study of skin resistance have differed somewhat from those of Richter and others inasmuch as we find that the distribution of vasomotor fibers does not necessarily coincide with the sensory distribution of the nerve and that their rate of recovery may be very different.[11] (Fig. 1.)

As mentioned earlier, the cardinal points of satisfactory neuroraphy were defined by surgeons of the last war, and we, too, agree that any method of repair which achieves, (1) approximation of nerve ends without tension, (2) accurate orientation of the internal topography of proximal and distal stumps, and (3) retardation of, or at least, no increase in the tendency for ingrowth of scar tissue into the suture line or the encirclement of the nerve and its repair by cicatrix, meets all the theoretical and practical demands of nerve suture. The majority of the neurological surgeons in the service today have employed the epineural suture as was used in the last war, modifying the technic only by employing fine tantalum wire instead of fine silk. The wire seems to have an advantage over silk in that it incurs less foreign body reaction. However, no matter what the suture material, we are of the opinion that the classical epineural suture is bound to encounter certain technical difficulties because the epineurium itself is a structure subject to wide anatomical variations in the case of abnormal nerves. In most cases, the epineurium is thickened which may go on to constricting keloid-like encasement. The epineurium may contract, forcing the protrusion of fasciculi, or, it may stretch allowing the fascicles to retreat within the

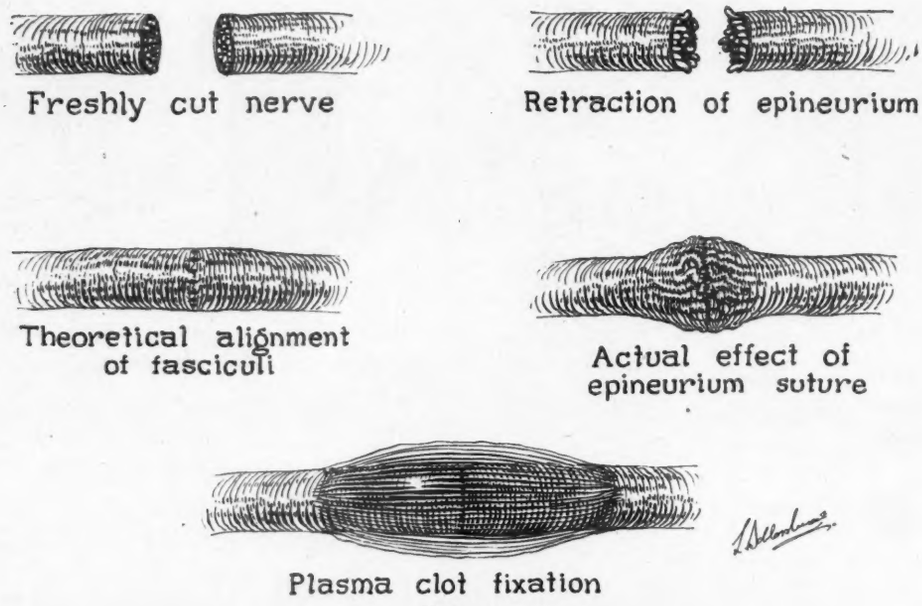

FIG. 2.

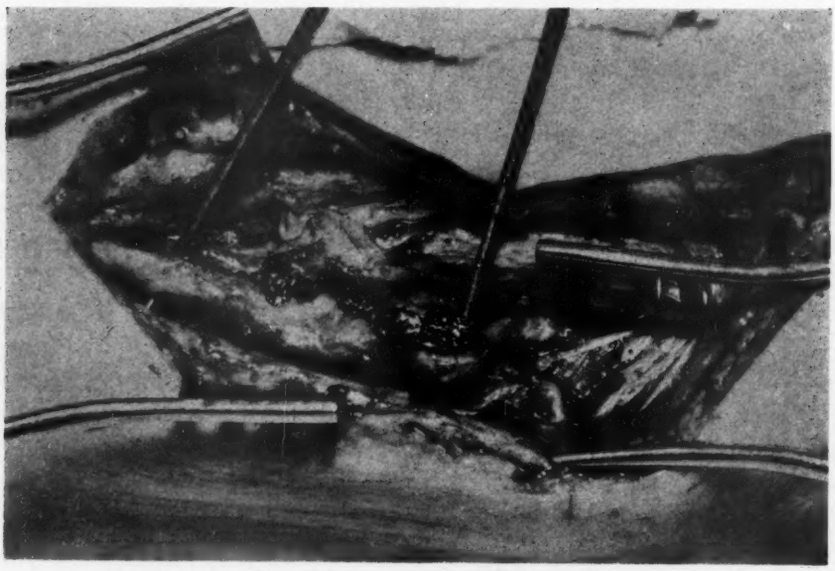

FIG. 3. Radial nerve which had been transplanted and wrapped in tantalum foil. Not injured originally, nerve now shows considerable epineural fibrosis.

sheath. I have believed that the repair of nerves, by the use of plasma clot, as first suggested by Young and Medowar[12] and the technic for which was later perfected by Tarlov,[13] overcomes to a great extent the difficulties inherent in the old epineural suture technic. (Fig. 2.)

The practice of enveloping the repaired nerve in some sort of protective covering such as blood vessel, fat, fascia or cellophane in order to prevent the involvement of the nerve in scar had been tried before this war by many with equally bad results. It is unfortunate that during the war, a wave of enthusiasm over the newly discovered metal tantalum lead to the wholesale wrapping of nerves in tantalum foil without rational or experimental justification. (Fig. 3.)

Since the organization of the Neurosurgical Service at St. Albans, we have carried out plasma clot repair of approximately 150 nerves. Final evaluation of this series will be the subject of a later communication, but a study of the results so far obtained permit several interesting ob-

servations. The best results were obtained in the group designated as "delayed repairs," i.e., after healing of primary wound, while the worst results were in the group designated "secondary repairs," those cases which have had one or more previous attempts at repair. The rate of recovery varied enormously, three cases showed evidence of reinnervation in eighteen, twenty-one and twenty-eight days, the most rapid being a facial and the next two median nerves. None of these were cases of "early repair." Very complete final recovery has occurred in some cases in which no evidence of reinnervation was detectable for nine months to one year after repair. The factors determining rate of recovery are not known.

Five nerve grafts were attempted, three of these were fresh cadaver grafts and two autogenous cable grafts. In none of them has there been any evidence whatever of axonization of the distal end of the nerve. Re-exploration of the graft in two cases allowed for stimulation of the graft under local anesthesia and it appeared that neurotization of the graft had occurred for a distance of 2 cm. from the suture line but that beyond this point the graft was completely fibrosed without evidence of axonization. (Fig. 4.)

Clinical experience with nerve grafts is in sharp contrast with the results obtained in laboratory experimentation, where in many cases both clinically and histologically a complete reinnervation of the distal end of the nerve occurred.[14] In consideration of nerve grafts, certain factors should be clearly understood. In the first place, the completely successful nerve graft would suppose that the Schwann cells continued their existence as in a tissue culture when transferred from the donor to the host and in order for them to do this rapid re-vascularization of the graft must occur. Histological studies of re-vascularization of nerve grafts in animals[15] show that each end of the graft receives outgrowing blood vessels from the adjacent nerve stumps but that the central portion of the graft receives its blood supply from the contiguous tissue. The first requisite then for a graft to succeed is that it be placed in a well vascularized bed. The very fact that a nerve graft is needed, that is to say, that there has been a gross loss of nerve substance, implies that there has been considerable destruction of soft tissue and that the possibility of obtaining a vascular bed for a nerve graft is a remote one. In our own cases, it was obvious that the first two grafts were placed in fibrosed avascular beds in which their chance for survival was indeed remote. In our next two grafts, an attempt was made to overcome this obstacle and the epineurium of the graft itself was split and opened up like the hood of a cobra. After attaching the central stump of the nerve to one end of the graft, this "cobra hood" was then reflected back over the belly of a normal adjacent muscle with each separate nerve fascicle in direct contact with the muscle surface. It was hoped that this would allow the graft to become vascularized and neurotized, and at a second stage, be reflected from its muscle bed and attached to the distal end of the nerve. However, at re-exploration after one year in this position, it was found that the graft had become replaced by fibrous tissue with mature neurotization of only the proximal centimeter of the graft.

The use of autogenous cable grafts from every point of view is more apt to be successful, since it eliminates the factor of anaphylactic destruction; but where grafts are needed in large defects, the amount of material needed is so great and entails the sacrifice of so many small cutaneous nerves, that again the procedure is impractical. We know that grafts of small dimensions do and will succeed and this is of great importance in certain and specific instances, particularly in the facial canal and in the fingers where no amount of mobilization of nerve ends is possible and where even a graft of a half a centimeter is of real value. In large nerves of the

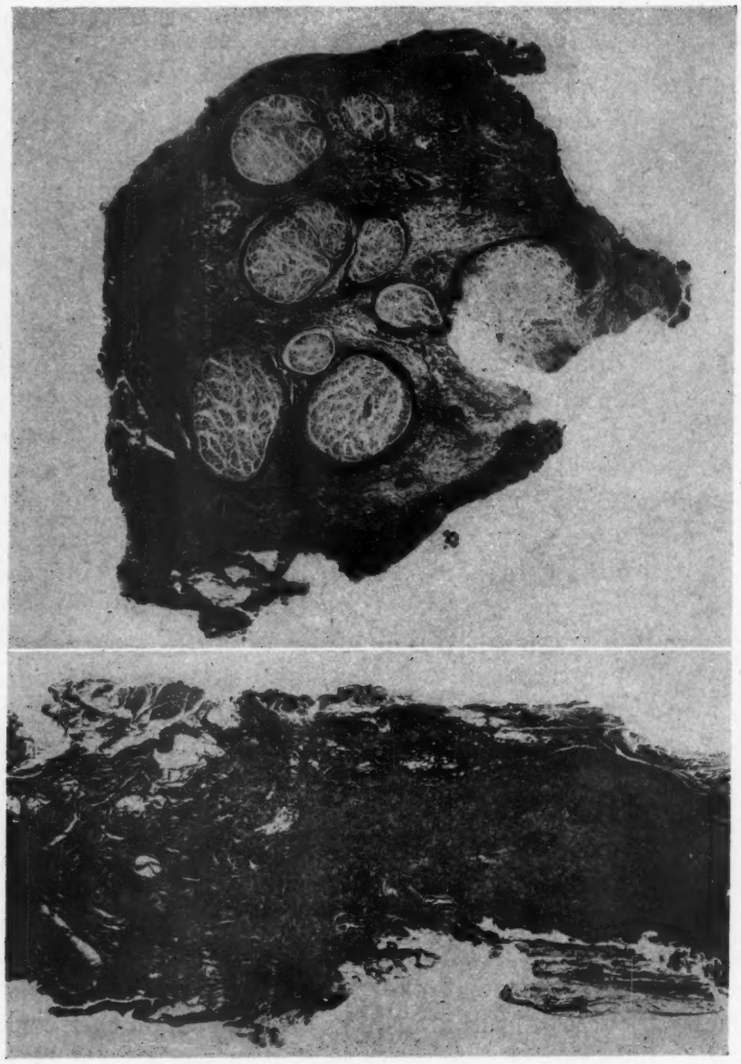

FIG. 4. Low power microscopic section showing good fasciculi central to graft (A), and complete fibrosis of graft (B).

extremities, however, where mobilization, transplantation and angulation of adjacent joints can be made to contribute as much as 8 or 10 cm. of nerve available to fill a gap of corresponding length, the use of short grafts is of no value. It is interesting then that at the close of the last war at a time when there was much enthusiam for the use of grafts, Naffziger[16] decried the profligate use of grafts and stated clearly that the necessity for grafting could be reduced to a minimum by the radical employment of transplantation, mobilization and angulation. In 1927, Babcock reemphasized this fact.[17] Naffziger also stated that he believed that nerves were capable of surviving a considerable amount of stretching and that, if necessary, operation should be done in two stages in which the nerves were first fixed together by a so-called end bulb suture and the limb allowed to extend stretching the nerve, so that at the second operation the ends could be amputated and approximated. One case in which we employed this procedure was entirely unsuccessful. At reoperation, the central stump was found to contain fascicles of nerve fibers but the distal stump had shrunken to one-sixth the diameter of the central stump with complete loss of internal topography and collaginization of the remnants of the Schwannian tubes.

It is fair to assume that both central and distal segments of the nerve had been

subjected to the same or nearly the same tension, but it is obvious that the distal end was destroyed by this stretch while the central stump was relatively unaffected.

We have in our series, six cases of plasma clot repair in which there was complete failure of reinnervation of the distal stump. In all six, an attempted repair at a previous operation by an inexperienced operator had resulted in the suturing of a central tendon to the distal stump of the nerve, and in these cases the constant tugging of the tendon on the distal stump had led to complete fibrosis of the distal end not only at its point of attachment but throughout the extent of the nerve. We, therefore, reached the conclusion that the distal stump of a severed nerve will not tolerate stretching. The central portion of a severed nerve, however, is a normal structure with normal blood supply and it should have normal ability to withstand stress and strain. The work of Denney Brown[18] describing the early and late changes that follow sudden stretching of nerves in animals is not in conflict with our idea, that the central end of a nerve will tolerate gentle but prolonged stretching. These observations have lead us to attempt a procedure which we call a two-stage stretch operation and which we have employed instead of nerve grafts. The technic for this procedure will be described in another communication.

SUMMARY

The importance of exact and detailed methods of evaluating nerve deficit, and the careful recording of all factors which might influence nerve recovery is emphasized. In our hands the plasma clot repair of nerves has seemed to offer definite advantages over other methods of repair. We believe that the unavoidable obstacles to successful employment of grafts limits their use to small nerves and peripheral branches. Gentle and prolonged stretching of the central stump may be the answer to bridging the gap of major trunks.

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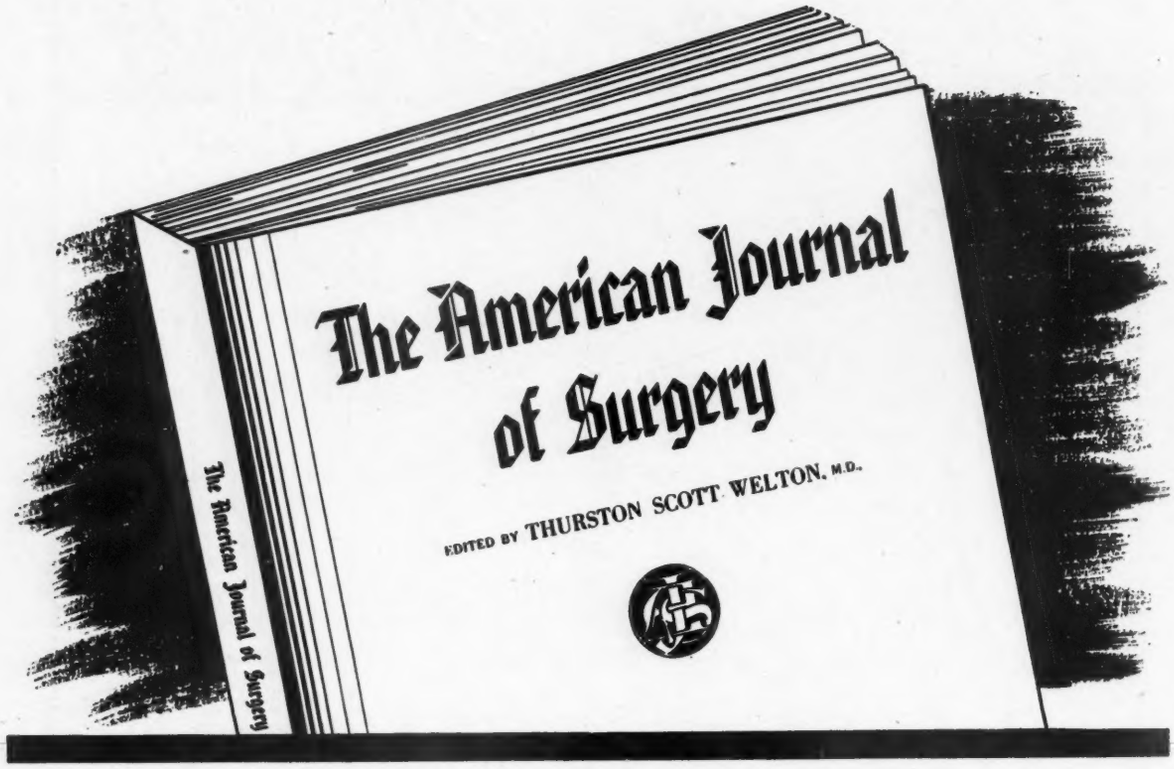

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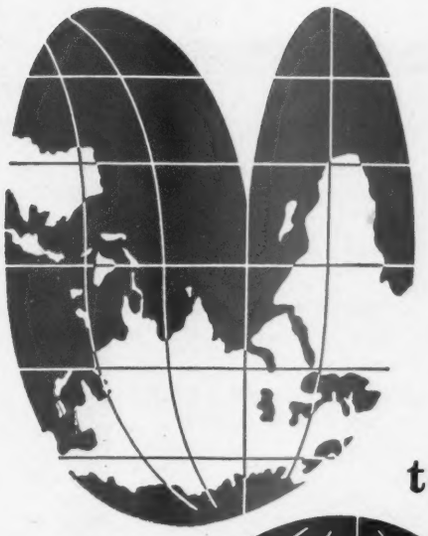

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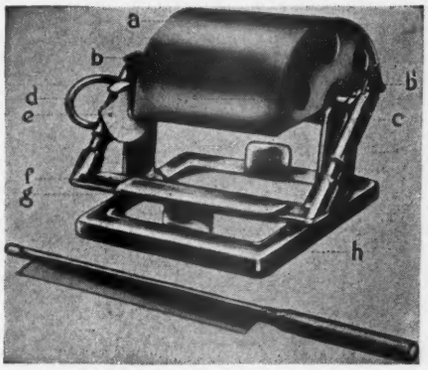

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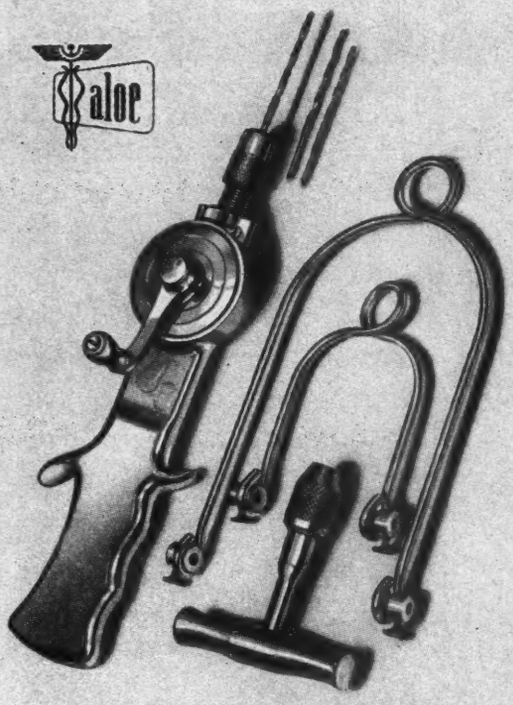

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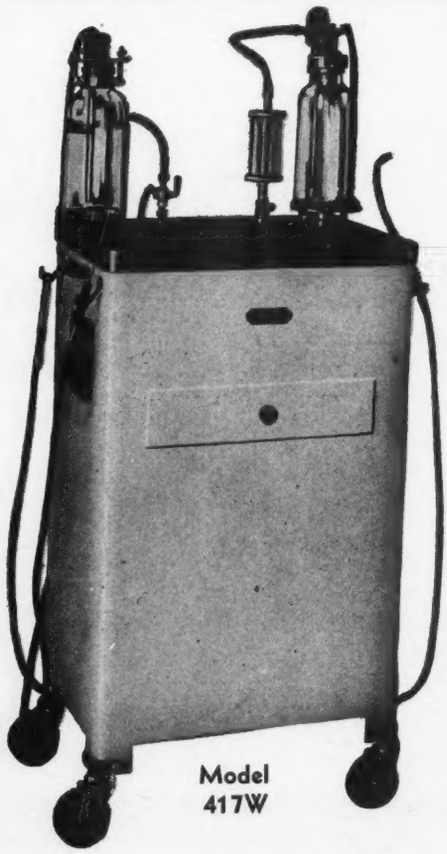

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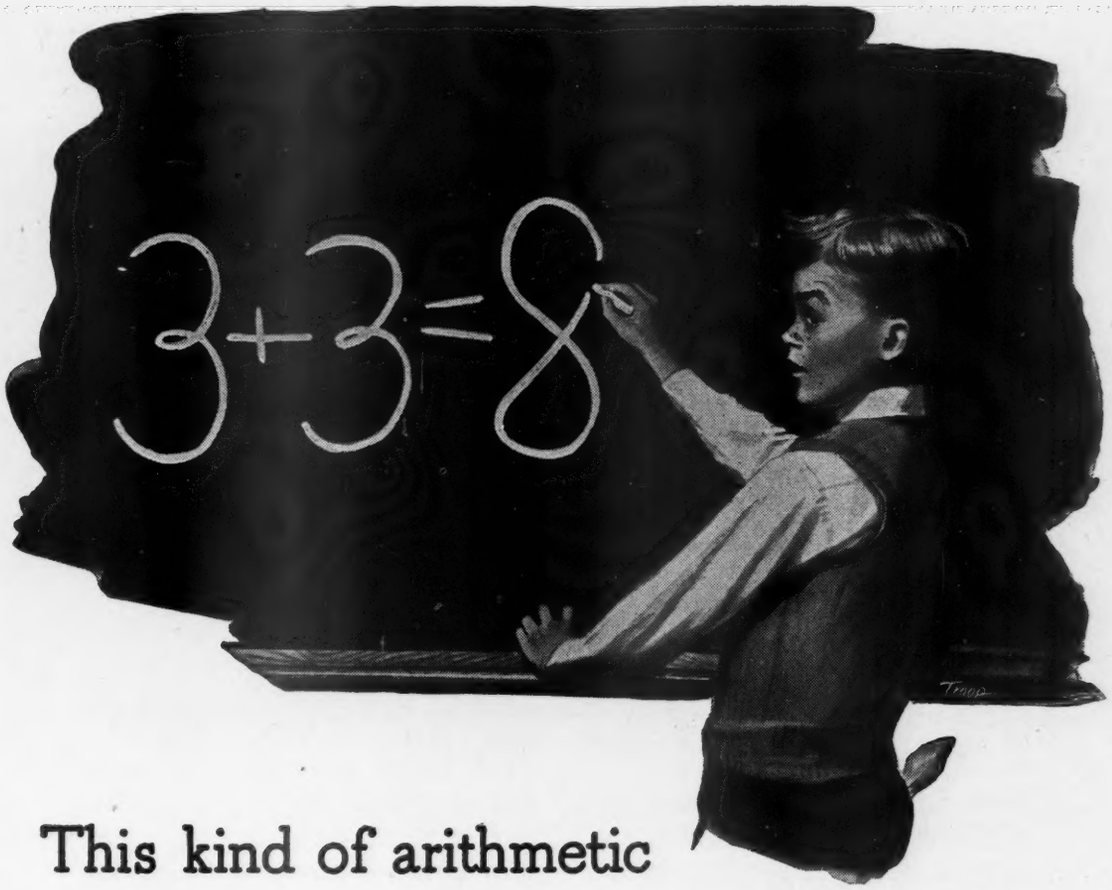

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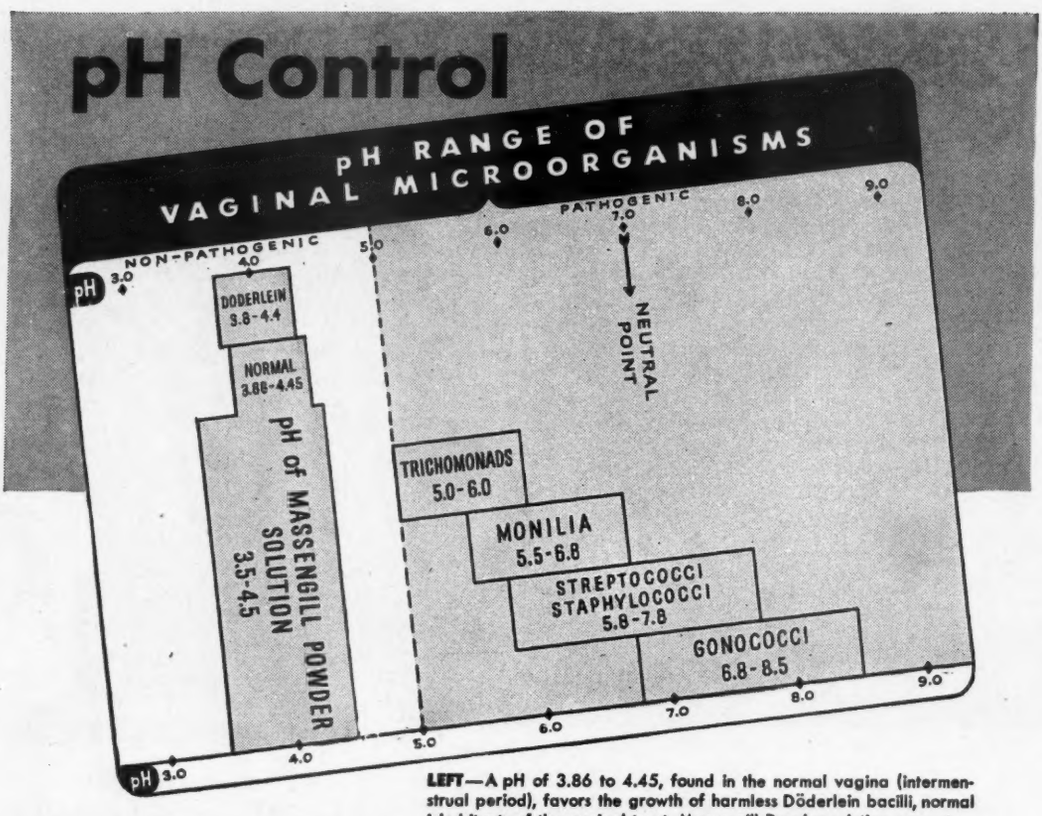

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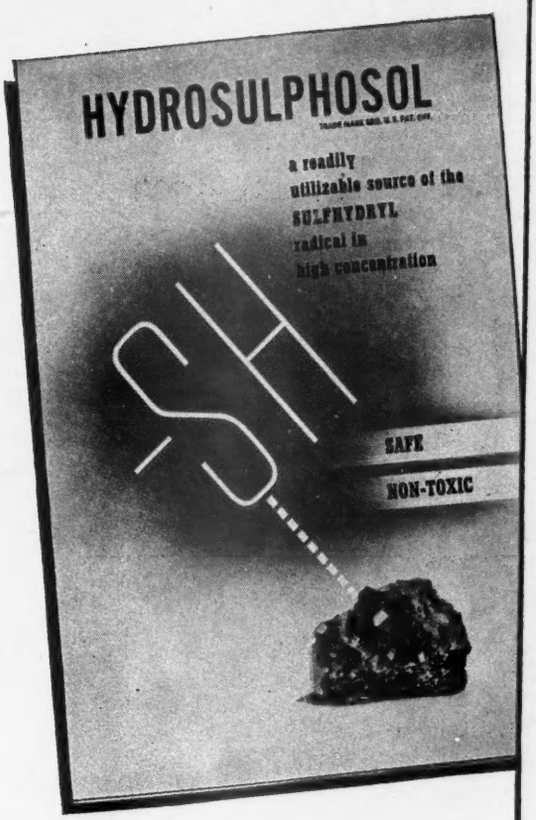

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TUB BATH: Add two ounces of Hydrosulphosol Solution to a full tub of water at 100 to 102 deg. F. for five to twenty minutes with a patient moving all of his affected joints while submerged in the bath. An authority on this type of therapy points out the hot bath is useful in subacute or chronic generalized rheumatoid arthritis, although some arthritic patients, particularly those who are emaciated and weakened, do not tolerate exposure to heat and are easily exhausted from prolonged hot baths. In such cases the foot bath would be better indicated.

Fluids should be given freely after the bath (or during the bath if marked sweating occurs). If there is excessive perspiration, 2 to 6 tablets of sodium chloride (1 Gm. each) may be given. All patients should rest in bed for at least an hour after the bath.

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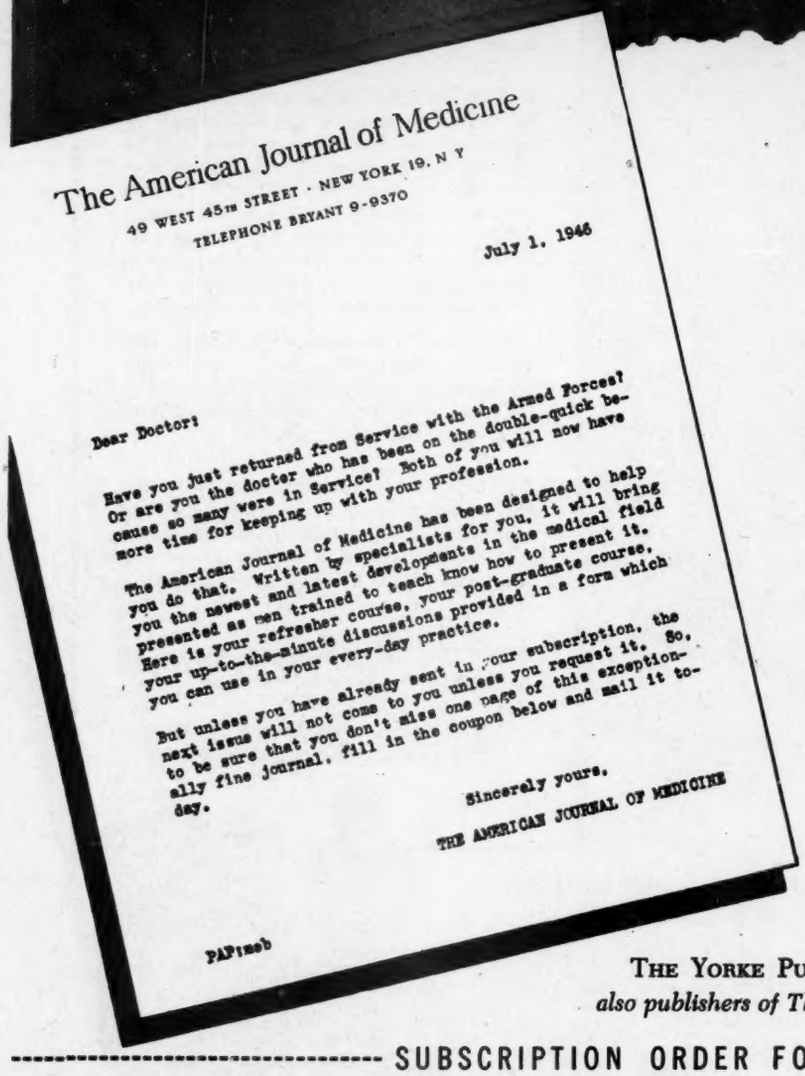

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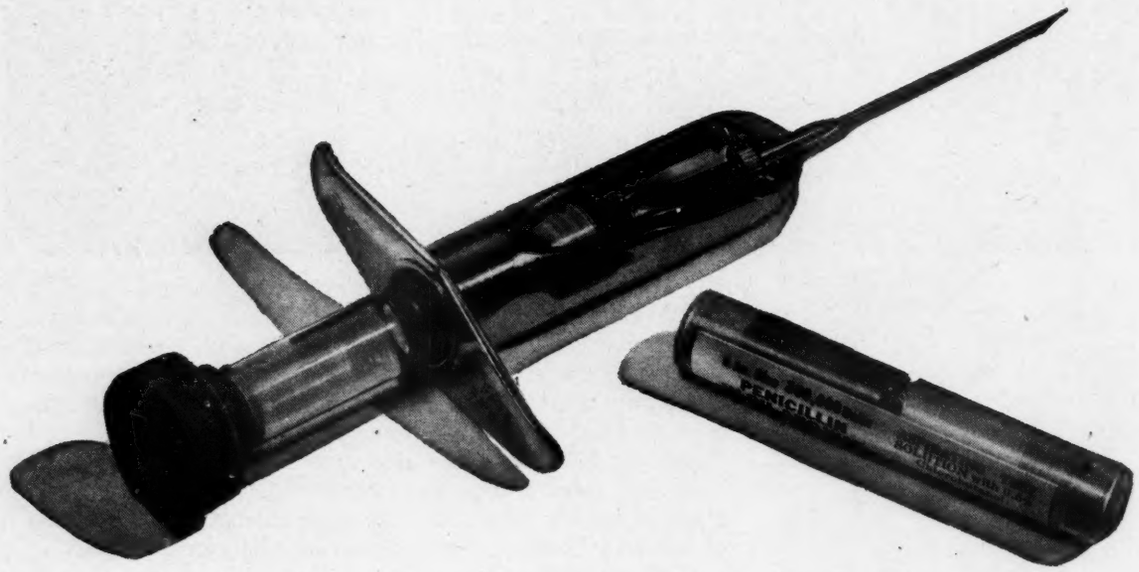

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1. Kirby, W. M. M.; Leifer, W.; Martin, S. P.; Rammelkamp, C. H. and Kinsman, J. M.: J.A.M.A. 129:940 (Dec. 1) 1945. 2. Romansky, M. J., and Rittman, G. E.: Science 100:196 (Sept. 1) 1944.

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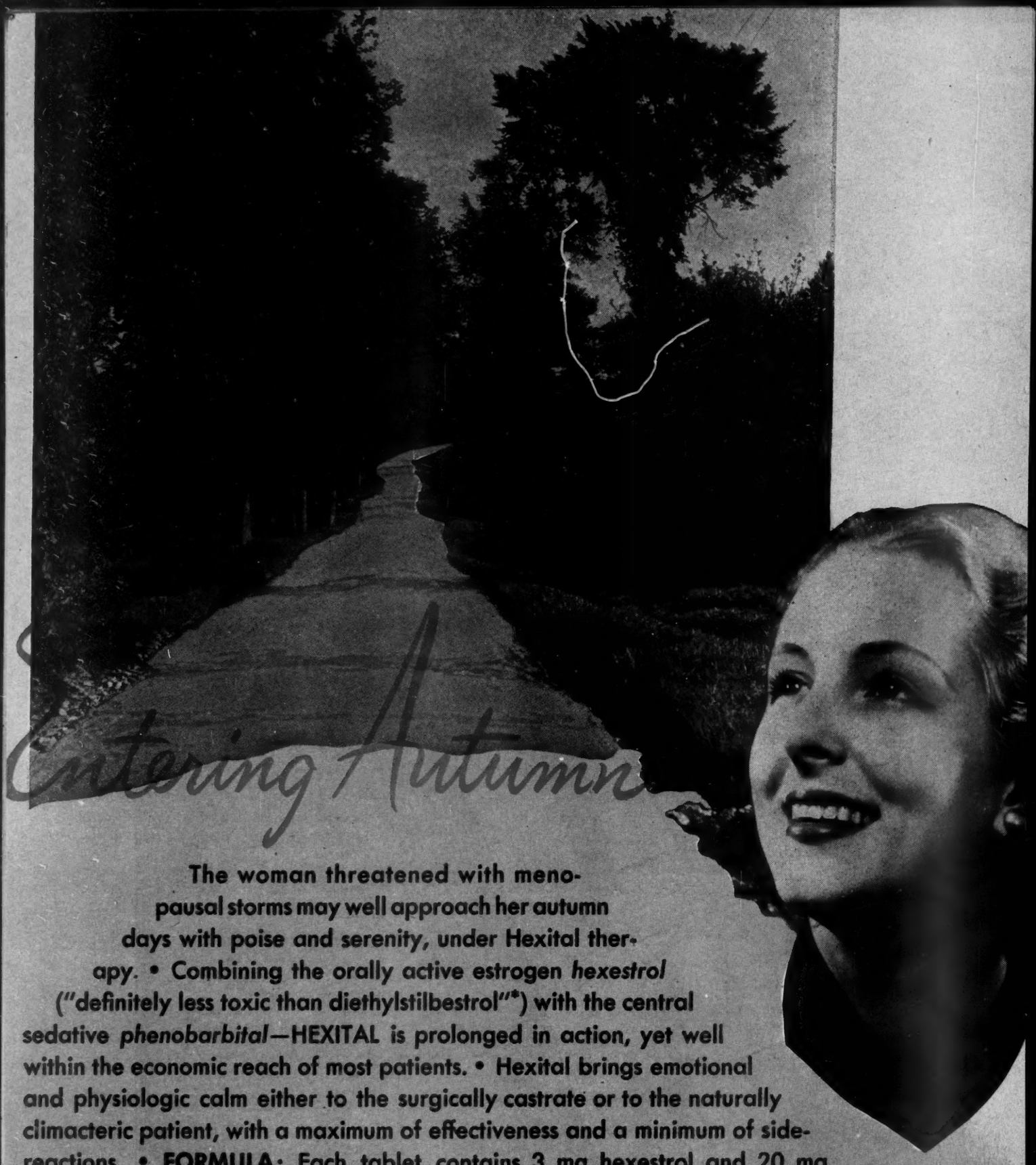

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